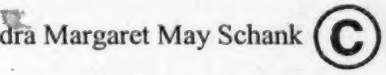
University of Alberta

# Assessing the effects of trout stocking on native amphibian communities in small boreal foothills lakes of Alberta

By

Candra Margaret May Schank 

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

In

Ecology

Department of Biological Sciences

Edmonton, Alberta

Fall 2008

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*Your file Votre référence*
*ISBN: 978-0-494-47406-8*
*Our file Notre référence*
*ISBN: 978-0-494-47406-8*

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Abstract

Creating or enhancing recreational fisheries through sport-fish stocking is an accepted practice, but can also have negative concequences on the recipient ecosystem. I studied 11 boreal foothills lakes, 5 with and 6 without stocked trout. All lakes supported native forage fish and 3 amphibian species: wood frog (*Lithobates sylvaticus*), boreal chorus frog (*Pseudacris maculata*), and western toad (*Anaxyrus boreas*). To assess effects of stocking on amphibian populations, I examined the relative abundance and size of adults and young-of year, and timing of metamorphosis over 3 years. For wood frogs and western toads, none of these parameters differed significantly between stocked and unstocked lakes. However, adult boreal chorus frogs were significantly more abundant on unstocked lakes. Wood frog abundance and size differed between 11 fish-bearing lakes and a fishless lake, suggesting fish presence, per se, affects frog populations. I conclude that generally, stocked trout are not affecting amphibian populations in Alberta's boreal foothills.

Acknowledgments

This study could not have occurred without the financial and in-kind support from Alberta Sustainable Resource Development (ASRD), Alberta Conservation Association (ACA), Industrial Post Scholarship NSERC, Alberta Conservation Association Grant Eligible - Conservation Fund, Canada Circumpolar Institute – C/BAR fund, and the Alberta Sport, Recreation, Parks, Wildlife Foundation Development Initiatives Fund.

I would like to acknowledge and send out a thank you to several people for making this study possible. The staff at the Rocky Mountain House government building in Alberta Sustainable Resource Development and Alberta Conservation Association offices were incredibly supportive and accommodating by providing housing, field, computer, and file resources, as well as volunteering their time. In particular I would like to say thanks to Steve Herman (ASRD), Rocky Konynenbelt (ASRD), Rod Burns (ASRD) and Cory Rasmussen (ACA). I would also like to thank the Grazing Association, local anglers, the Kutz Family, and Mr. and Mrs. Taylor for allowing us to have access to their land and providing us with local knowledge of the area.

I am forever grateful to my dearest friend and side-kick in this project, Leslie Nasmith, for all her hard work in and out of the field for the past three years. She was my rock and this study would not have been the same without her. I would also like to thank my family for their support over the years. Without their kind words and gentil pushes, none of this would have been possible. Also, special thanks goes out to all the hard working enthusiastic field assistants that I had over the last three years – Colette Feehan, Katie Thompson, Justin Hanisch, Chantelle Allen, Paul Giang, Alissa Moenting, Darryl Edwards, Andre Caron, and Teela Stroll. This study would not have been possible without all of you. Thank-you!

I would also like to send out a special thanks to the many members of my committee and lab: Bill Tonn, Garry Scrimgeour, and Lee Foote, the Pasz-Tonn team. Oh, and I could never forget my bio-core friends, Stephanie Nakada, Sarah lord, and Amy Darling for their assistance and advice and for always being there for me. Even with all the support and advice I have gathered from my friends, I am thankful and would like to give a 5-star special thanks to my supervisor, Cindy for her guidance, insight, contributions and patience with all my "silly questions" over the past three years.

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## 1. Introduction

### 1.1 **Sport-Fish Stocking**: Management and Human Benefits

*Stocking and recreational fishing*

Because of Canada's abundance of streams and lakes, the number of recreational fisheries exceeds hundreds of thousands and spans the country. These fisheries are not always of high quality, and have suffered from over-fishing and habitat deterioration (Post et al. 2002). To offset over-fishing and habitat deterioration, one management strategy is the creation or maintenance of recreational fisheries in Canada through the stocking of native or non-native species of sport-fish. Stocking lakes for recreational use occurs when: (1) existing fish populations have collapsed and need to be re-established, (2) sport-fish are introduced into water bodies where they were not present historically, and (3) there is a desire to increase the diversity of angling experiences (Cooke and Cowx 2004).

Over the last 100 years, sport-fish stocking has become a common and widespread practice. To promote recreational fisheries throughout North America and worldwide, governments and other organizations have stocked native and non-native sport-fish into lakes and streams. Because of this practice, 60 % of lakes in the western United States have gone from being fishless to containing non-native sport-fish (Bahls 1992).

Stocking sport-fish can have positive outcomes for local anglers and communities by augmenting the numbers of fishing locations and opportunities. More fisheries could potentially benefit the economy of nearby towns by increasing tourism. Despite such positive outcomes and underlying good intentions to enhance natural resources, stocking can have negative consequences. One problem is public perception of long-term stocking programs. Mixed views exist towards stocking. Anglers are either neutral to the thought of catching stocked fish, or they do not like fishing for stocked fish and prefer wild stocks (White et al. 1995). Anglers come to expect that fisheries will be created and maintained through stocking; this promotes a supply-and-demand approach to recreational fisheries (Wiley et al. 1993). As the number of anglers rises or the desire for more fishery choices increases, anglers lobby for additional "good" fisheries (Van Zyll De Jong and Gibson 2004). As a way to accommodate anglers' requests, new lakes are found and stocked without documentating effects of the introduced species (Gilliland and Boxrucker 1995). Therefore, anglers, as well as government and non-government organizations, need to be better informed about the consequences of stocking sport-fish. For example, if populations of native prey species are not sufficient to support introduced fish, the fishery may quickly collapse (Kitchell et al. 2000). Similarly, creation of a recreational fishery on a lake will attract anglers, and activities of these anglers may alter the lake shoreline and surrounding terrestrial habitats (Cooke and Cowx 2004).

*Sport-fish stocking in Alberta*

Alberta is home to 51 native fish species, 4 intentionally introduced species, and 10 illegally or accidentally introduced species (Alberta Sustainable Resource Development

2006). Of these 65 species, 18 are angled and consumed. Currently, approximately 1,500 streams and 800 lakes in Alberta contain native sport-fish populations.

Over the years, Alberta has seen a steady demand for recreational fisheries, which provides social, recreational, and economic benefits. In 2005, approximately 300,000 active Albertan anglers, collectively spent 3.3 million days fishing, caught 12.3 million fish, of which they harvested 1.6 million. Fishing contributed $440 million to the provincial economy (Alberta Environment 2006). To ensure recreational fisheries provide regional and provincial benefits, and recognizing that fish populations are limited resources, fisheries must be properly managed to ensure sustainable populations. Indeed, under the Provincial Alberta Fish Conservation Strategy (2000), fisheries managers strive to maintain all sport-fish populations in a healthy state such that populations, sizes and age classes do not fluctuate drastically.

To augment recreational fisheries based on native populations of sport-fishes, 300 lakes are regularly stocked with sport-fish. Of these 300 lakes, the majority are stocked with non-native fish (R. Konynenbelt, Alberta Sustainable Resource Development, personal communication). Species most commonly stocked are rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*). Rainbow trout are native to the Athabasca River drainage but have also been successfully introduced into Alberta drainages where they are not native: North Saskatchewan, Red Deer, Bow, and Oldman River drainages. Rainbow trout were also introduced into waters of northeastern Alberta in 1958. Brown trout are not native to North America and were first introduced into Alberta water bodies when populations were stocked into the Raven River and Jasper National Park in 1924. The brook trout is native to northeastern North America but exotic to Albertan waters and was first successfully introduced into Banff National Park in 1910, and spilled over into drainages of the western half of Alberta: Peace, Athabasca, North Saskatchewan, Red Deer, Bow, and Oldman River drainages (Nelson and Paetz 1992).

The main objective of stocking is to improve or construct recreational fisheries, while providing anglers with a diversity of recreational opportunities. To meet the varied needs of anglers, two types of stocked fisheries exist in Alberta, "put-and-take" and "catch-and-release". Put-and-take systems are set up as family fisheries; fish are stocked at high densities, increasing chance of capture. However, a receiving water body can only support a limited fish biomass before it surpasses carrying capacity. Therefore, family fisheries are stocked with relatively small-sized sport-fish. Catch-and-release fisheries are aimed at competitive anglers who seek to hook and land, then release, large trophy fish. Therefore, fish are stocked at larger sizes but lower densities to support a trophy fishery.

Stocking lakes with sport-fish has increased the number of lakes managed as recreational fisheries. However, the predisposition to stock new lakes when the demand for new fisheries arises is a quick-fix solution to angler needs. This quick-fix practice is carried out without knowing the consequences of stocking, which could lead to future problems (e.g., fisheries collapse). Pre-stocking studies should be conducted on trophic

interactions, food web composition, and nutrient cycling to determine effects of the introduction of trout or other piscivorous fish into a water body. Knowledge gained from pre-stocking research will not completely eliminate quick-fix strategies, but will allow fisheries management to better understand interactions between introduced trout and their environment (included native species). And with time, may lead to improved management of recreational fisheries and stocking programs. Documenting and dealing with these effects are among the challenges facing stocking programs in Alberta and elsewhere.

### 1.2 **Sport-Fish Stocking:** Effects on Receiving Ecosystem

Whole-lake studies across North America have shown repeatedly that intentional stocking of piscivorous salmonids, (such as brook, brown, and rainbow trout) can affect the distribution and abundance of native biota (Schindler et al. 2001; Zimmer et al. 2002; Simon and Townsend 2003; Durham et al. 2004; Knapp 2005). These sport-fish species are commonly stocked in Albertan water bodies (Nelson and Paetz 1992). Introduced non-native fish often dramatically change community structure and ecosystem processes within lakes. The following section reviews the effects of fish predation on aquatic systems, focusing on the effects of introduced salmonid species.

*Food web interactions and nutrient cycling*

Native and introduced predacious fish can affect populations of prey species directly through mortality, and indirectly by altering prey species' behaviour, reproduction, and use of habitat and resources (Tonn 1985; Bryan et al. 2002; Museth et al. 2002; Pink et al. 2007). The introduction of a piscivorous predator into a system can cause new direct and indirect top-down interactions, sometimes leading to a trophic cascade that profoundly alters the entire ecosystem. Changes can occur because: (1) the system did not previously support this trophic level or (2) the system already contained piscivorous taxa and interspecific competition or new predation patterns result. When a novel trophic level is introduced to a system, lower levels may experience catastrophic changes, shifting the biotic structure and function of the system. For instance, if a lake is dominated by forage fish, herbivore (such as zooplankton) populations may be controlled, but if piscivorous fish are added to the lake, a shift in hervivore density, species composition and biomass may occur as forage fish populations are reduced through predation (Carpenter et al. 1985). The effects salmonids have on zooplankton communities can indirectly affect physical characters of lakes, e.g., in systems with introduced salmonids, large *Daphnia* dominated and heavily grazed phtytoplankton, which, in turn, improved water clarity (Scavia et al. 1986).

As shown through various manipulative studies, fish can sometimes have no impacts on invertebrate communities (Zimmerman and Vondracek 2007) or affect macroinvertebrate abundances (Meissner and Muotko 2006) and abundance of zooplankton (Elser et al. 1995; Knapp et al. 2005; Parker and Schindler 2006). However, impacts caused by interactions between fish and aquatic invertebrates can extend to abiotic features of

aquatic systems (Scavia et al. 1986). Shifts in nutrient limitation through alteration of residence times of carbon, phosphorus and nitrogen in the water column can be caused by shifts in zooplankton community composition that result from fish predation (Elser et al. 1998). Algal blooms caused by terrestrial nutrients loading can be suppressed when piscivorous fish reduce planktivorous fish populations that, in turn, lead to increases in large-bodied zooplankton grazers that are more effectively able to filter water, suppressing algal blooms (Schindler et al. 1997). Similarly, at a lower trophic level, Cole and others (2000) found that plankivorous minnows reduced the number of large zooplankton, which caused a spike in nutrient enrichment. Therefore, it can be assumed that if piscivorous fish were added to the system, minnow populations may be reduced, eliminating the nutrient spike.

*Effects on invertebrates*

Emergence patterns, species richness, and size structure in invertebrate communities can be affected by introduced trout. Nakano and Murakami (2001) found that streams that were stocked with arctic char (*Salvelinus alpinus)* exhibited reduced emergences of benthic insects. Donald and others (2001) found that zooplankton species richness was low in pristine fishless lakes compared to lakes that contained a complex fish assemblage of native and non-native fish from three families, Catostomidae, Cyprinidae, and Salmonidae (including five species of trout). Mean zooplankton size may also increase as a result of piscivorous salmonid stocking (Scavia et al. 1986).

*Interaction with native fish*

Introduced fish not only affect lower trophic levels, they can also alter native fish assemblages by preying directly on some native taxa, reducing their numbers, while allowing other taxa to increase in abundance and expand the habitat occupied (Gilliam and Fraser 1987; Chapleau and Findlay 1997). Similarly a non-native sport-fish, smallmouth bass (*Micropterus dolomieu*), has been found to displace native lake trout (*Salvelinus namaycush*) through competition for food resources, causing the trout to forage on less optimal, alternative prey (Vander Zanden et al. 1999). In Lake Tahoe, the native top predator, Lahontan cutthroat trout (*Oncorhynchus clarkia henshawi*), was extirpated after the introduction of the non-native lake trout, which out-competed the Lahontan cutthroat trout and took over its trophic niche (Vander Zanden et al. 2003).

In systems with introduced fish, native fish can alter their feeding behaviour. Lepak and colleagues (2006) showed that after the removal of a non-native competitor (smallmouth bass), the native piscivore (lake trout) shifted from a profundal diet primarily of chironomids to a diet composed of 50 % littoral fish [brown bullhead (*Ictalurus nebulosus*), landlocked Atlantic salmon (*Salmo salar*), pumpkinseed (*Lepomis gibbosus*), rainbow smelt (*Osmerus mordax*), and slimy sculpin (*Cottus cognatus*)], restoring the system back to original prey assemblage. In the presence of introduced trout, to reduce mortality, forage fish have been found to increase shoal-size (effects of brook trout, Pink et al. 2007) and decrease foraging movements (effects of cutthroat trout, McHugh and Budy 2006).

In Alberta, stocking of shallow lakes that experience winter hypoxia has been coupled with other alterations of the environment, such as artificial aeration. Large electric bubbler aerators are used to provide oxygen. The primary goal of aeration is to over-winter sport-fish so that stocking does not need to occur on a yearly basis. Aeration itself can produce a range of effects on lake environmental conditions and biotic communities (Ellis and Stefan 1991; Ashley and Nordin 1999; Millar and Mackay 2003). In British Columbia lakes, aeration has been found to increase water clarity (due to a complete disappearance of cyanobacteria), increase overall standing crop of zooplankton (with a shift to dominance by cladocerans) and decrease coverage by native *Elodea*, an aquatic macrophyte (Ashley and Nordin 1999). These outcomes can be either desirable or unwanted depending on the circumstance. For example, the public may view clear water as desirable because clarity is associated with clean water. On the other hand, a decline of *Elodea* may reduce habitat for invertebrates, small-bodied fish, and amphibians, and a reduction of food for aquatic birds.

### 1.3 **Sport-Fish Stocking:** Effects on Native Amphibians

I have discussed stocking as a management activity and shown that research on sport-fish stocking has provided overwhelming evidence that this management activity has the capacity to cause trophic cascades, and alter food webs and nutrient cycling. For 20 years, amphibian declines have been a growing conservation concern. Researchers are investigating the causes and effects of these declines. Introduced and invasive predators have been found to be major contributors of amphibian declines (Knapp 2005). The following review of the literature on effects of native and non-native predators on the distribution and abundance of amphibians will serve to generate predictions concerning the impacts of introduced trout on amphibian populations in Alberta and elsewhere.

*Amphibian distribution and habitat*

Freshwater fish species tend to be more geographically isolated compared to terrestrial vertebrates. Fish dispersal options are limited by permancy of waterbodies (e.g., temporary versus permanent water bodies), inlets and outlets, flood regimes, and humans as a vector for dispersal. The existence of temporary and permanent water bodies on a landscape enable an assortment of predator and prey species to establish and persist. Not all water bodies contain the same prey and predator assemblages; permanent water bodies display a higher diversity of predators compared to ephemeral or semi-permanent waters (Wellborn et al. 1996). For example, ephemeral systems cannot support long-lived vertebrate predators.

The presence or absence of an amphibian species in a water body can be linked to the distribution of its predators. In the complex life cycle of pond-breeding amphibians, the aquatic egg and larval stages are the most susceptible to predation (Formanowicz and Brodie 1982; Gillespie 2001; Touchon et al. 2006; Gomez-Mestre and Warkentin 2007; Verburg et al. 2007). Amphibian eggs are not protected by shells and are often laid in open water or on submerged vegetation. Larvae are not efficient swimmers and are conspicuous when foraging. Common amphibian predators include macroinvertebrates

(dragonfly naiads, larval and adult giant water bugs and diving beetles, and leeches), other anuran species, and large- and small-bodied fishes.

*Amphibian predator avoidance and adaptation to predator presence*

The majority of introduced anuran predators [e.g., American bullfrog (*Rana catesbeiana*) and piscivorous fish] are limited to permanent water bodies. To reduce predation on eggs and larvae, adult amphibians can actively avoid permanent water bodies with higher predation pressure as breeding sites (Murray and Wirsing 2004; Cruz et al. 2006; Welsh 2006). Complete avoidance of predation is almost impossible. Whether tadpoles are found in ephemeral or permanent waters, they display life history and behavioural strategies to avoid predation. In ephemeral waters with predators, tadpoles have been found to grow and develop rapidly and become active when predators are not foraging (Figiel and Semlitsch 1990; Kiesecker and Blaustein 1997; Buskirk and Arioli 2005). Conversely, tadpoles in permanent waters grow and develop slower, display reduced activity and forage at night (Figiel and Semilitsch 1990). Jordan and Arrington (2001) showed that amphibian species that regularly coexist with various native predatory fish are not highly represented in fish diets in terms of frequency of occurrence or numbers of individuals, demonstrating that larval antipredator strategies are effective. Yet even in systems that contain native fish, amphibians may be vulnerable to predation from introduced fish because native and introduced fish species differ ecologically and behaviourally (Levine and D'Antonio 1999). Kats and Ferrer (2003) proposed that if alien predators and vulnerable amphibian species are found co-existing, this may reflect a recent colonization by the predators and the situation is likely temporary.

Through evolutionary and ecological time, prey can acquire traits that offset predation. Once the threat of a predator translates into fitness consequences, prey species adapt and express antipredator behaviours and morphological shifts. On an evolutionary time-scale, these adaptations in amphibians include the evolution of cryptic colouration and production of toxins that make individuals unpalatable to predators. Adaptations at ecological time-scales are faster, and may appear within a generation or two. It is widely accepted that native and non-native predators (specifically introduced fish) induce one or more antipredator strategies in amphibian larvae (Figiel and Semilitsch 1990; Chivers et al. 1999; Kiesecker et al. 2001; Relyea and Hoverman 2003; Altwegg and Reyer 2003; Kraft et al. 2005).

Amphibians mechanisms of predator avoidance and defense include: (1) timing of egg hatching – in the presence of a predator, larvae will either hatch earlier or later to avoid mortality (Chivers et al. 2001; Vonesh 2005); (2) modification of behaviour - larvae can reduce activity and or alter foraging patterns (Figiel and Semlitsch 1990; Kiesecker and Blaustein 1997; Buskirk and Arioli 2005); (3) modification of morphology – a larva's body can change in size and shape, and growth can be reduced or enhanced in the presence of a predator (Relyea and Werner 2000; Kraft et al. 2005); (4) unpalatability – larvae and adults may contain predator-deterring toxins (Daly 1995); (5) alarm cues – larva and post-metamorphic amphibians can respond to chemosensory cues from predators or from injured conspecific individuals (Chivers et al.1999; Murray et al. 2004); and (6) timing of metamorphosis – the date at which juveniles move out of the

water and into terrestrial environments may occur earlier and juveniles emerge at a smaller body size in the presence of predators (Kiesecker et al. 2002). Not all species exhibit all larval antipredator responses; only one or two of the aforementioned responses are sufficient to reduce predation risk.

Larval amphibians have been adopted as model organisms for demonstrating how prey species adapt to co-exist with native predators. Plasticity exists in hatching time in response to the threat of egg predation in the Pacific treefrog (*Hyla regilla*) and Cascades frog (*Rana cascadae*; Chivers et al. 2001; Keisecker et al. 2001). When a predatory leech (*Desserobdella picta*) was added to mesocosms with Pacific treefrog egg masses, eggs hatched earlier and at an earlier developmental stage (Chivers et al. 2001). McIntyre and colleagues (2004) showed that native predatory *Belostoma* water bugs caused phenotypic responses in tadpoles of Amazon River frog (*Rana palmipes*). They found that plasticity existed in behaviour, morphology, and pigmentation as tadpoles exhibited lower activity, deeper tail fins, darker pigmentation, and faster growth when exposed to chemical cues from water bugs. American toad (*Bufo americanus*) tadpoles can learn to recognize conspecific alarm cues and odours from predatory larval dragonflies (*Anax* sp.; Mirza et al. 2006).

Not all anuran species respond the same to specific predators, regarless if predators are native or non-native. Richardson (2001) found that different predators (pumpkinseed sunfish (*Lepomis gibbosus),* spotted sunfish (*L. punctatus*), red-spotted newt (*Notophthalmus viridescens viridescens),* eastern newt (*N. viridescens louisianensis)*, and common green darner (*Anax junius*) elicited a different activity level response from larval amphibians. Murray and colleagues (2004) showed that 4 different adult amphibians displayed different avoidance behaviour towards native garter snakes (*Thamnophis elegans*) and non-native bullfrogs, reflecting a predation vulnerability gradient. Avoidance behaviours are most likely linked with the likelyhood of predator induced mortality and the energetic costs of these behaviours.

*Direct effects of introduced salmonids on amphibians*

Because of habitat loss and degradation, and intentional and accidental spread of exotic and invasive species, amphibian populations have declined worldwide (Alford and Richard 1999; Blaustein and Kiesecker 2002; Beebee and Griffithi 2005). In North America, stocking of large-bodied predatory sport-fish poses a serious threat to many species (Figiel and Semilitsch1990; Bradford et al. 1998; Knapp and Matthews 2000; Knapp et al. 2001). In many cases, permanent water bodies where fish-stocking occurs represents optimal habitats for both amphibians and large-bodied fish. Permanent water bodies offer year-round high water-levels; providing favorable habitats for long-lived vertebrates (e.g., fish). Some amphibians need larger, deeper water bodies to complete metamorphosis. For example, bullfrogs and green frogs (*Lithobates clamaticus*) require permanent water bodies because they can take 1 - 3 years to reach metamorphosis (Collins 1979). Recreational fisheries, through stocking, are established on these permanent deep lakes, because they assure fish survival. However, due to this fish-amphibian habitat over-lap, stocked fish can interact negatively with native amphibians (Pilliod and Peterson 2001).

Introduced salmonids prey on and compete with, native amphibians (Kiesecker 2003), forage fishes (Charles et al. 2003), macroinvertebrates and zooplankton (Hilderbrand and Kershner 2004; Haddix and Budy 2005), ultimately changing the structure of food webs in wetlands and lakes (Drake and Naiman 2000; Knapp et al. 2001; Nystrom et al. 2001). In most cases, salmonid species share little or no evolutionary history with the affected amphibian species (Diamond and Case 1986; Gillespie 2001) and the outcome of introductions can be unpredictable. The local presence of mountain yellow-legged frog (*Rana muscosa*) displayed strong negative relationships with the presence of introduced trout (rainbow and brook trout) in Yosemite National Park, John Muir Wilderness, and in Kings Canyon National Park (Knapp and Matthews 2000; Knapp 2004, 2005; Davidson and Knapp 2007). In Alberta's Waterton Lakes National Park, populations of long-toed salamander (*Ambystoma macrodactylm*) have apparently been extirpated by introductions of rainbow trout, cutthroat trout, golden trout *(O. aquabonita),* and brook trout (Pearson 2004). Similarly, Finlay and Vredenburg (2007) found that densities of tadpole and post-metamorphic *R. muscosa* were significantly higher in fishless lakes than in fish-bearing lakes.

By using stable-isotopes, Finlay and Vredenburg (2007) showed that there was complete dietary overlap in use of benthic prey eaten by adult *R. muscosa* feeding at lake margins and non-native trout. Therefore non-native trout are acting as a competitor with adult *R. muscosa* as well as a potential predator of larval *R. muscosa* life history stage.

*Indirect effects of introduced salmonids on amphibians*

Non-native trout can trigger anuran antipredator behavioural strategies (i.e., reduced activity and feeding: Figiel and Semilitsch 1990; Kiesecker et al. 2001). Moreover, trout can affect amphibians indirectly by shifting distribution, abundance, and behaviours of other amphibian predators such as forage fishes. Trout will feed on various forage fish, including northern redbelly dace (*Phoxinus eos*: East and Magnan 1991), lake herring (*Coregonus artedi*), rainbow smelt (*Osmersus mordax*) and sculpin species (*Cottus cognatus* and *Myoxocephalus Thompson*: Charles et al. 2003). It is assumed that many forage fishes will prey on amphibian egg masses and small larvae if the opportunity presents itself (Eaton et al. 2005). Introduced trout can displace native fish (Penczak 1999; Nakano et al. 2002; Simon and Townshend 2003) and reduce forage fish activity rates by limiting movements into and out of refuges (Little Colorado spinedace, *Lepidomeda vittata*: Bryan et al. 2002). Through direct and indirect effects of trout predation on forage fish, amphibian populations may benefit from reduced predation or competition.

Introduced trout can cause other indirect effects on native amphibians. Trout species tend to be generalists, foraging on various taxa, at different trophic levels (Nelson and Paetz 1992). Trout are known to forage on and eliminate large invertebrate grazers and predators, reported by Giliwicz and Rowan (1984) and Knapp and colleagues (2001). In such cases, amphibians may indirectly benefit. With the eradication of key invertebrate predators, larvae may abandon costly antipredator behaviour and forage more freely. With the decrease in large invertebrates that prey on amphibian eggs and larvae,

amphibian populations may be able to survive and co-exist with introduced trout (Hammond et al. 2007).

Not all introductions of trout have produced negative effects; some amphibians have shown either a neutral or positive response to trout introductions (Knapp 2005; Pearl et al. 2005; Welsh et al. 2006). Knapp (2005) found that Yosemite toad (*Bufo canorus*) and Sierra newt (*Taricha torosa sierrae*) populations in lakes in Yosemite National Park were not affected by the presence of rainbow and brook trout. Pearl and others (2005) found that the native northwestern salamander (*Ambystoma gracile*) populations in Oregon's Willamette Valley were not significantly reduced in lakes that contained introduced fish [including mosquitofish (*Gambusia affinis*), bullhead *(Amieurus sp.*), and yellow perch (*Perca flavescens*)]. In sub-alpine water bodies in the Klamath-Siskiyou Bioregion of northern California, the occurrence of rainbow, brook, and brown trout populations was uncorrelated with the occurrence of western toad (*Bufo boreas*), and positively correlated with the occurrence of roughskinned newts (*Taricha granulose*: Welsh et al. 2006)

In summary, native predators and introduced fish, including trout, have varying effects on aquatic ecosystems and native organisms, particularly amphibians. How trout stocking will affect the ecosystem and native biota is difficult to predict. Outcomes are a result of two factors; the nature of the ecosystem being manipulated can have an effect as can the species and communities involved.

### 1.4 The Structure of this Thesis

Across North America, management strategies that include deliberate introductions of non-native salmonids into lakes and streams have enhanced recreational fishing opportunities (Stein et al. 2000). This management practice has been applied in Alberta for almost a century (Nelson and Paetz 1992) and Alberta Sustainable Resource Development's Fish and Wildlife Division actively stocks water bodies with various sport-fish species, especially rainbow trout.

However, the ecological cost of stocking can be high as native ecosystems are dramatically and perhaps irrecoverably altered (Cooke and Cowx 2004). In some cases, native populations can be extirpated, and species threatened. Declines in some amphibian species, such as the red-legged frog (*Rana aurora*) and mountain yellow-legged frog, have become widely cited examples of extreme negative impacts of trout stocking (Stebbins and Cohen 1995; Kats and Ferrer 2003; Dunham et al. 2004; Pearson 2004; Vredenburg 2004; Beebee and Griffiths 2005; Knapp 2005). Most examples of stocking "disasters" that include amphibian declines have occurred in alpine systems in the Sierra Nevada, Rocky, Siskiyou, and Cascade Mountain ranges (Schindler 2000; Knapp 2005; Reid 2005). These lakes are located at high elevations, have short growing seasons, low productivity, low biodiversity, simple food webs, and were historically fishless.

My thesis investigates the effects of trout stocking on amphibians populations in small boreal foothills lakes on the east-slopes of the Rocky Mountains. To date, lakes in this geographic area have seldom been studied even though stocking of brown, brook, and rainbow trout has been occurring for decades. Compared to the aforementioned alpine systems, these lower elevation lakes are productive with relatively longer growing seasons and higher biodiversity (including native fishes) which result in more complex food webs.

In this thesis, I start with a general overview of stocking as a method of managing sports fisheries, and review how introduced sport-fish, particularly salmonids, affect aquatic ecosystems. After the introduction, I provide information on my study area, study organisms, and methodology. I then present results of 3 years of field research detailing the effects of stocked salmonids on native amphibian populations in the boreal foothills of Alberta, Canada. To do this, I address the following questions by comparing amphibian populations in stocked and unstocked boreal foothill lakes:

1. Does the presence of trout affect the occurrence and relative abundance of amphibians, relative to systems lacking trout?
2. Does the presence of trout affect the size structure of amphibian populations, relative to systems lacking trout?
3. Does the presence of trout affect recruitment in amphibian populations, including patterns of metamorphosis and emergence of young-of-year, relative to systems lacking trout?
4. Does the presence of fish affect amphibian relative abundance, size, and patterns of metamorphosis, relative to a system lacking fish?

I conclude by reviewing my results in the context of current management strategies for recreational fisheries, particularly in Alberta, and offer some recommendations based on my research findings.

## 2. Study Area and Species

### 2.1 Terrestrial and Aquatic Habitats

To assess the effects of trout stocking on native amphibian communities, I studied populations in 12 boreal foothills lakes located in a 704-$km^2$ area (32 km north-south by 22 km east-west) in the Clearwater District near Rocky Mountain House and Caroline, Alberta, Canada. This work was part of the FIESTA (Fish/Frog and Invertebrate Effects of Stocked Trout and Aeration) Project, conducted in collaboration with Alberta Sustainable Resource Development, Fish and Wildlife Division (ASRD) and Alberta Conservation Association (ACA).

The District of Clearwater is at the eastern edge of the boreal foothills within the Lower Boreal Cordilleran eco-region. The bedrock geology consists of folded and faulted

sandstone formations that include siltstone and mudstone members (Hamilton et al. 1999). Tills are the predominant surface materials due to Pleistocene Cordilleran glaciation (Boydell 1978). The landscape contains rolling hills with elevations ranging from 1140 to 1560 m (Szwaluk and Strong 2003). The district is in a climatic and ecological transition zone between higher elevation coniferous Cordilleran Forest and lower elevation Boreal Mixed-wood Forest (Strong 1992). The area is dominated by forests of trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), lodgepole pine (*Pinus contorta*), and white spruce (*Picea glauca*). Peatlands, muskegs, wetlands and small lakes also characterize the region (Strong 1992).

In the District of Clearwater, the majority of lake-outlet streams flow into tributaries of the Red Deer River. However, some outlets flow into the North Saskatchewan River or lakes are landlocked. Study lake sizes ranged from 1.8 to 28 ha with maximum depths from 1.5 to 15 m (Table 1). These lakes are oligo-mesotrophic to meso-eutrophic (range of total phosphorus = 8 – 53 µg/L) with pH ranging from 6.7 to 8.6 (see Results: Limnological characteristics; Table 4). *Typha latifolia, Potamogeton spp.*, and *Nuphar variegatum* are dominant aquatic macrophyte species in the study lakes (C. Schank, University of Alberta, unpublished data).

Five of the 12 study lakes contain stocked trout: Ironside, Mitchell, Yellowhead, Strubel, and Birch. Stocking records were provided by ASRD Rocky Mountain House Office, Eastern Slopes Region (Tables 2 and 3). Stocking has occurred since 1950 (n = 3 lakes), 1983 (n = 1 lake), or 2005 (n = 1 lake). These 5 lakes are stocked either on an annual or biennial basis. Lakes are stocked with hatchery-reared rainbow, brown, or brook trout at varying sizes and densities to create put-and-take (4 lakes) or catch-and-release (1 lake) recreational fisheries. Between 2005 and 2007, numbers of trout stocked into study lakes varied from 500-20,000 fish/lake at an average size of 6 – 29 cm (total length; Table 3). Lakes that support family fisheries (put-and-take fisheries) were stocked with more fish at a smaller size to facilitate higher catch rates, whereas the 1 lake managed for trophy fish and a catch-and-release fishery, was stocked with fewer but larger fish (Table 3).

In Alberta, numerous lakes are small shallow and productive. Due to shallow depths, the water column can become hypoxic during winter ice-cover, causing large die-offs of aquatic organisms. Trout and especially forage fish can survive episodes of reduced oxygen levels in the winter, but if oxygen concentrations drop below tolerance limits of a species, mortality ensues (Nelson and Paetz 1992). Sustainable dissolved oxygen (DO) levels to ensure survival of large-bodied fishes and to maintain healthy fish populations at all life history stages have been identified by U.S.A. Environmental Protection Agency (Environmental Protection Agency 1988). For salmonid species, the sustainable DO level identified to prevent any mortality is between 5 and 11 mg/L (Roussel 2007; Rust 2008), whereas, almost 100 % mortality occures at DO levels below 5 mg/L (Doudoroff and Shumway 1970; Dean and Richardson 1999). Minimal DO requirements differ with species, temperature, and time of day (Doudoroff and Shumway 1970). For small-bodied fishes, sustainable DO levels are slightly lower than large-bodied fishes, with a value of 4 mg/L (Koehle and Adelman 2007; Rust 2008).

In Alberta, before stocking is initiated, winter DO levels are assessed so that fisheries managers can predict if winterkill is likely. In lakes with low winter oxygen levels and winterkill events, lakes can be stocked annually. However, this is expensive and inefficient, and might not create trophy catch-and-release fisheries with multiple age classes and large fish. An alternative is to artificially aerate winterkill-prone lakes with large (1/2 – 1 horse power) bubbler aerators during winter months. Of my 5 stocked study lakes, 2 are aerated during winter months (Ironside and Mitchell Lakes). Because native amphibians in this region complete their larval development during the first summer after hatching and hibernate in adjacent upland terrestrial landscapes (Russell and Bauer 2000), aeration does not directly affect amphibian populations or habitat. Therefore, I chose to consider stocking and stocking-plus-aeration as a single treatment.

Beginning in 2005, I studied amphibian populations at 5 stocked lakes (see above), chosen by ASRD and ACA personnel, and 6 unstocked lakes: Gun Range, Dog Leg, Fiesta, Picard, Teal, and Gas Plant. All stocked and unstocked lakes contained native populations of cyprinids and/or stickleback (Table 2). In 2006, I added a fishless lake, Dog Paw, to my study. Dog Paw served as a reference lake that allowed me to examine the effects of the presence of any fish species on amphibians in boreal foothills lakes. In some subsequent analyses, I grouped the original 11 lakes with native and stocked fishes into a fish-bearing treatment that I compared to my single fishless lake.

### 2.2 Fish Assemblages

The community structure of stocked and native fish species in my study lakes is largely consistent from lake to lake (Table 2). Stocked lakes usually contain a single trout species, either brook or rainbow trout. One lake, Mitchell Lake, contained both rainbow trout and brown trout. Brook, brown, and rainbow trout are all known to feed on terrestrial and aquatic insects, leeches, mollusks, crustaceans, fish (Nelson and Paetz 1992) and amphibians (Gillespie 2001; Verburg et al. 2007). Therefore, throughout the thesis, I will treat all trout species as a single entity (hereafter referred to as "trout"), as I assume their effects on amphibians are comparable.

Forage fish most common in the study lakes are brook stickleback (*Culaea inconstans*), fathead minnow (*Pimephales promelas*), and dace [finescale dace (*Phoxinus neogaeus*), northern redbelly dace (*Phoxinus eos*), pearl dace (*Margariscus margarita*), and *Phoxinus* hybrids; Table 2]. All dace species are grouped together and referred as "dace" because in the field it was hard to distinguish among the 3 species and *Phoxinus* hybrids (Nelson and Paetz 1992). Brook stickleback is tolerant of low oxygen levels and feeds primarily on small aquatic insects and crustaceans. Fathead minnow is commonly found with brook stickleback and is also tolerant of low oxygen levels. It feeds on algae and to a lesser extent zooplankton and aquatic insect larvae (e.g., cladocerans and chironomid larvae, respectively). Dace diets consist of insects and other aquatic invertebrates, algae, and zooplankton. Dace are also tolerant of low oxygen levels, but not to the same extent as brook stickleback and fathead minnow (Nelson and Paetz 1992).

## 2.3 **Study Species:** Amphibians

Historically, 4 anuran species were recorded in the District of Clearwater: wood frog (*Lithobates sylvaticus*), boreal chorus frog (*Pseudacris maculata*), western toad (*Anaxyrus boreas*), and northern leopard frog (*Lithobates pipiens*). Alberta, in the late 1970's and early 1980's, saw drastic population declines of the northern leopard frog and it has been extirpated locally. With the patchy distribution of the long-toed salamander (*Ambystoma macrodactylum*) along the eastern range of the Rocky Mountain Foothills, I thought populations may occur in my study area. However, no salamanders were found during my 3-year study.

The wood frog is distributed throughout the aspen parkland and the boreal forest and can survive at elevations up to 2500 m. It is one of the most recognized and abundant anurans in North America, occurring throughout Canada, Alaska and the northeastern United States (Conant and Collins 1998). Wood frogs are explosive breeders, and in Alberta foothills begin breeding at ice-off (mid to late April) and finish ca. 2 weeks later (C. Schank, University of Alberta, unpublished data). Wood frogs hibernate on land and are able to survive winters because they are freeze tolerant owing to a chemical cryoprotectant (Costanzo and Lee 1993). The boreal chorus frog is also a terrestrial hibernator that exhibits freeze tolerance, enabling it to survive in cold regions of North America. The species is found virtually everywhere in Alberta, excluding areas where pesticides are used (Alberta Sustainable Resource Development 2002). Boreal chorus frogs are prolonged breeders. Calling starts around the same time as wood frogs but extends for another month at my study lakes (C. Schank, University of Alberta, unpublished data). Both wood frog and chorus frog populations are considered "Secure," or non-threatened within the province (Alberta Environment 2005). The western toad is found in a variety of habitats in western and central Alberta, including boreal forest, subalpine and alpine areas up to 2300 m in elevation. The breeding season of the western toad is prolonged and extends from approximately mid May to mid June. The species is not nearly as abundant or ubiquitous as the wood frog and boreal chorus frog, and is ranked as "Sensitive" within the province (Alberta Environment 2005). The western toad is also a terrestrial hibernator, but must burrow beneath the frost line, as it lacks freeze tolerance.

## 2.4 **Predictions Concerning Effects of Stocked Trout on Amphibian Populations**

Based on interactions between fishes, both native and introduced species, and amphibians documented from other systems (Schindler 2000; Knapp 2005; Reid 2005), I predicted the following patterns for anuran amphibians in stocked versus unstocked lakes in the boreal foothills. 1) Due to the low diversity of amphibians in Alberta and slight overlap in breeding times, competition for food, breeding and rearing habitats may not exist on the landscape. In addition, the number of suitable water bodies may be limited on the landscape. Therefore, all 3 amphibian species should visit and breed on all 12 study lakes during the open-water season, irrespective of the presence or absence of trout. 2) Adult anurans should be less abundant on stocked lakes since adults have been found to avoid laying eggs in lakes with high larval predation risk (Petranka and Holbrook 2006).

3) Because trout affect anuran amphibian populations directly by preying on larvae (Knapp 2005), I predicted that young-of-year (YOY) anurans would be less abundant on stocked lakes. Furthermore, since YOY wood frogs and boreal chorus frogs are more palatable than YOY western toads, wood frogs and boreal chorus frogs should be less abundant on stocked lakes. 4) In the presence of trout, tadpoles will emerge from the stocked lakes at a smaller body size and earlier date, as an antipredator strategy, since it is assumed that tadpoles will reduce potential predation risks by escaping from the aquatic environment (Wassersug and Sperry 1977; Kiesecker and Blaustein 1998; Kiesecker et al. 2002). Thus, smaller adult anurans should also occur on stocked lakes, assuming that individuals that metamorphose at smaller sizes in response to predation never "catch up" to attain large body sizes (Berven 1990). 5) The presence of any fish species (native or introduced) will affect amphibian populations. Therefore, adult and YOY amphibians should be less abundant and smaller at fish-bearing lakes, compared to the fishless lake. YOY amphibians should metamorphose at an earlier date at the fish-bearing lakes versus fishless lake.

# 3 Methods

## 3.1 Limnological Characteristics

Environmental characteristics of aquatic habitats can be important determinants of amphibian occurrence and abundance (Sexton et al. 1990; Bradford et al. 1998; Parker 2001; Schindler et al. 2001; Vasconcelos and Calhoun 2004; Brown and Shine 2007; Koch and Hero 2007). A variety of environmental features were measured for the 12 study lakes (Table 4). A temperature logger was deployed in each lake in both the epilimnion and hyperlimnion in June (2005 and 2007) or May (2006) and retrieved in August (2005 and 2006) or September (2007). Loggers were programmed to record temperature hourly. Water chemistry was sampled in June and August 2005, monthly from May through August in 2006, and in May and August 2007. Samples were collected by submerging a 1 L sterilized brown bottle 30 cm below the surface at the deepest point in the lake. Water samples were processed by the Biogeochemical Analytical Laboratory at the University of Alberta for total nitrogen (TN: µg/L), total dissolved nitrogen (TDN; µg/L), total phosphorus (TP: µg/L), total dissolved phosphorus (TDP µg/L) and chlorophyll-a (500 ml of water filtered through a filter paper; Chl-a: µg/L). These parameters documented lake productivity. For both nitrogen ($r = 0.891$) and phosphorus ($r = 0.822$) environmental parameters, dissolved concentrations were highly correlated with total concentrations. Thus, for this study, TN and TP were used instead of TDN and TDP.

In all 3 years, conductivity, pH, and surface temperatures were taken once a month from May through August by placing a probe 10 cm below the surface at the deepest spot of the lake. At the same locations, profiles of dissolved oxygen (DO: mg/L) and temperatures were measured every 1 m from the surface down to the bottom of the lake. The mean of descending and ascending readings were calculated for each meter interval.

### 3.2 Amphibian Surveys

A variety of sampling methods were used to assess relative abundance of anurans, size structure of populations, and timing of metamorphosis across study lakes. I used several methods to increase the likelihood of detecting differences among lakes and to increase sample sizes. Different methods also focused on different life history stages. During the 3 years of field work, I used call and egg mass surveys (2006), visual transect surveys (2005 – 2007), and pitfall trapping (2006).

*Call surveys*

Breeding individuals of several species of anurans are known to avoid water bodies that contain predatory fish (Petranka and Holbrook 2006). Therefore, I used call surveys to determine if male frogs and toads were attempting to breed on lakes with and without trout, and to determine the density of males calling in groups around lakes using a "Call Index" (Stevens and Paszkowski 2004). Call surveys were coupled with egg mass searches to document oviposition patterns for female wood frogs.

In 2006, call surveys were performed on the 11 original lakes between April 24$^{th}$ and May 23$^{rd}$. The twelfth lake (fishless: Dog Paw Lake) was not yet part of the study. At each lake, sampling based on point counts was performed during 4 periods: April 24$^{th}$ - 27$^{th}$; May 2$^{nd}$ - 5$^{th}$; May 6$^{th}$ - 13$^{th}$; May 17$^{th}$ - 23$^{rd}$. During each period, lakes were visited once. The first 3 survey periods recorded calling for wood frog and boreal chorus frog; the 4$^{th}$ recorded western toad.

Lakes were surveyed within a 3-h window (2130 to 0130) starting 30 min after sunset, under appropriate weather conditions (no to light rain and wind). Surveys were halted when temperatures dropped below 0 °C and males stopped calling. Due to the extent of lake shoreline, call surveys were performed by canoeing around the lake. Point count locations were ca. 10-20 m offshore, at intervals of at least 200 m. The number of point counts per lake ranged from 3 to 6, depending on lake size (Table 5). During a count, the canoe was stopped and surveyors listened for 5 min. After 5 min, the number of males calling (per species) in each distinct group was quantified via a Calling Rank Index: Rank 0 – no males heard, Rank 1 – all males calling could be counted and identified, Rank 2 - all males heard could be counted but some call overlap occurred, and Rank 3 – too many males calling to determine the actual number (Stevens and Paszkowski 2004). During some point counts, surveyors heard more than one spatially distinct aggregation of calling males. Aggregations were determined by clustering males that replied to calls from group members, but were less responsive to and unsynchronized with males from other groups. The maximum number of distinct groups encountered at any point count location was 3.

*Egg mass searches*

Wood frog egg mass searches were conducted on lakes the day following nocturnal call surveys to verify the presence of females and document that oviposition was occurring. Boreal chorus frog and western toad egg masses are laid in small, short single strands underneath vegetation foliage, and proved too inconspicuous to census and were never

encountered. Wood frog egg masses are cryptic, but because they were large and deposited communally in shallow open water, they could be visually located (C. Schank, University of Alberta, unpublished data).

During the first set of point count surveys (April 24-27th), I established 3 locations on each lake that were regularly surveyed for eggs through May. I assumed that the likelihood of finding egg masses was higher at a Rank 3 site than at Rank 1 and 2 sites (more males calling equal more egg masses). Thus, due to time constraints (7 h window the day after call surveys) and the extensive lengths of shoreline where male wood frogs were heard calling, I selectively searched for egg masses at 3 Rank 3 calling localities, on lakes where Rank 3 choruses were heard. At lakes where I identified 2 or fewer Rank 3 locations, I surveyed sites with the 3 highest call ranks.

Searches were performed between 1000 and 1700. During each survey, 2 surveyors walked along the shoreline searching for wood frog egg masses. When the first egg mass was found in an area, coordinates were taken using global positioning system (GPS), the number of masses counted, and the area was flagged. Flagging allowed the location to be revisited during subsequent sampling periods to record additional egg masses and hatching.

*Transect surveys*

Visual searches create a "snap-shot" of relative amphibian abundance for a location at a specific time (Heyer et al. 1994). Results are affected by: 1) water levels of nearby water bodies, 2) vegetation type and density, 3) weather, 4) activity levels of animals, and 5) detection skill of the surveyor. Nonetheless, visual transects are an easy, repeatable method for censusing amphibians (Paszkowski et al. 2002). I performed 100 m visual transect surveys on 11 (2005 and 2007) or 12 (2006) lakes during each year of the study; dates and intensity varied among years (see below). Transect surveys recorded adult and YOY wood frogs, boreal chorus frogs, and western toads.

My protocol employed 1 or 2 surveyors who walked slowly along a predetermined 100 m of shoreline for a set amount of time (20 min for 1 surveyor in 2005, 10 min for 2 surveyors in 2006 and 2007; Appendix A) and counted and captured (if possible) all amphibians seen. Transect locations were determined by dividing lake perimeters into 100 m sections and then assigning consecutive numbers to each 100 m section. Then a random number generator was used to determine locations of transects that paralleled the shoreline. Along the water edge, in a zig-zag pattern, surveyors walked 100 m long, 6 m wide transect. Due to the small size of amphibians and their short bursts of movements, amphibian sightings occurred a maximum1.5 m from the surveyor. Animals that were successfully caught by hand were placed into a 10 L bucket with moist vegetation until a transect was completed. At the end of each transect, individuals were measured (see below) and released within 100 m of their capture. Surveys were carried out during daylight hours. When weather conditions were inappropriate (temperatures < 10 °C, hard rain, hail or strong winds) surveys were postponed as amphibians were either inactive or could not be easily seen.

In 2005, four 100-m transects running parallel to the shoreline were located and flagged on 11 lakes. For each lake, 7 surveys were carried out between July 16th and August 12th. Lakes were visited once every 3 days between 0800 and 1800. In 2006, 12 lakes were surveyed because the fishless lake, Dog Paw Lake, was added in May. For each lake, 11 surveys occurred between May 28th and August 22nd. The number of transects per lake varied from 2 - 6, as transects were designed to cover 20 % of each lake's shoreline (Table 5). Each lake was visited once every 5 days between 1300 and 1800. In 2007, transects established in 2006 were re-surveyed using the same procedures. However, unstocked Teal Lake was not surveyed because the shoreline was so densely vegetated that visual detection of amphibians was poor. Twelve surveys occurred on each lake between June 26th and August 16th. Each lake was visited once every 3 days, between 0800 and 1700.

During transect surveys, I attempted to catch every amphibian seen, however, I was not always successful. If an amphibian was seen but not caught, it was identified to species, its snout-urostyle length (SUL; mm) was estimated, and age was assigned (based on body size). To estimate SUL of animals not captured, I visually sized each individual using 5 mm SUL intervals (i.e., 30 - 34 mm, 35 - 39 mm). Ages of escaped wood frogs were determined using SUL estimates: animals > 30 mm were called adults and < 30 were YOY (this assessment was based on observed adult size from May and June; C. Schank, University of Alberta, unpublished data). This division was refined for individuals that were measured. Before July 1st of each year, all animals were assumed to have hatched in previous years and thus were termed adults. After July 1st, during emergence, I was able to use the size range of current YOY and previous adult amphibians caught to determine if an individual was a YOY or adult. Therefore I called wood frogs, western toads, and boreal chorus frogs, "adults" if SUL was greater than 27.5, 25, and 20 mm, respectively and YOY if SUL were less than those values. Captured animals were identified to species, sexed [using secondary sex characteristic: exaggerated thumb pads and release calls (wood frog and western toad), yellow throat (boreal chorus frog)], measured (SUL) with calipers and aged. For all amphibian species, age was based on SUL measurements. I was not able to sex YOY amphibians and small adults because they do not develop secondary sex characteristics until they reach maturity (wood frog: 2 years or more, boreal chorus frog: 1 year, western toad: 2 years or more; Behler and King 1979).

In 2005 and 2006, animals were also weighed with a Pesola spring-balance while being held in a dry plastic bag. Snout-urostyle length and weight measurements both represent size. However, measurements of weight in the field can vary depending on nutritional or hydration state of individuals, instrument accuracy, or environmental factors (wind or rain). Snout-urostyle length has been chosen over weight because it does not vary with individual nutrition state and abiotic influences (Figiel and Semilitsch 1990). I found that SUL and weight were highly correlated for YOY and adult wood frogs (YOY Pearson Correlation $r = 0.751$, $n = 271$; Adult Pearson Correlation $r = 0.919$, $n = 396$). Hence, only 1 size measurement was needed. Thus, in 2007 SUL alone was recorded. For all analyses, only SUL was used.

*Pitfall array trapping*

For this study, a "pitfall array trap" refers to a 20 m plastic fence with plastic buckets buried flush to the ground, acting as the trap (see below). On June 7th 2006, I began to construct 20 m pitfall array traps on a subset of 4 lakes, 2 stocked (Yellowhead and Birch) and 2 unstocked (Dog Leg and Gas Plant; Appendix A). Pitfall trapping provided an alternative method of assessing relative abundance, size and emergence patterns for amphibians. Pitfall trapping is an effective sampling method when the density of amphibians is low and animals are cryptic or nocturnal. Unlike visual surveys, traps sample continuously whenever animals are active. However, pitfall trapping is a passive sampling method and requires moving animals. Also, some species and size classes can avoid or escape bucket traps (C. Schank, University of Alberta, personal observation; Enge 2001). I used pitfall traps primarily to document relative abundance of YOY wood frogs and to compare with patterns documented by transect surveys.

By June 22nd, I had installed 6 pitfall array traps on all 4 lakes (24 pitfall array traps in total). The focus of pitfall arrays was to obtain as many YOY amphibians as possible. For that reason, arrays were located in Rank 3 areas because it was assumed that high densities of males calling would be connected to high densities of egg deposition, leading to high numbers of YOY. On each lake, at three Rank 3 locations, 2 pitfall trap arrays, 20 to 30 m apart, were situated ca. 3 m up from the shoreline. Arrays consisted of 20 m long, 60 cm high plastic drift fence, supported by 5 or 6, 1 m wooden stakes. The bottom lower edge of the plastic (15 cm) sat on the ground, and the remainder stapled to the stakes. Wet soil, drying into a hard barrier, was placed over plastic edges, under which amphibians were not able to pass. Along the lake-side of a pitfall fence, at 5 m intervals, a total of 4 plastic buckets (25 cm deep, 20 cm diameter) were buried flush to the ground. Extra plastic fencing material was placed over the top of each bucket mouth, secured with a large rubber band, and a 10 cm diameter hole cut to create a funnel. The funnel acted as a lid to prevent amphibians from escaping. Within each bucket, upright sticks and moist sponges and vegetation were placed to provide escape routes for small mammals and moisture for captured amphibians (Eaton 2004). On the 2 unstocked lakes, cattle grazed freely. To prevent cattle injury caused by stepping into buckets, 2 horseshoe-shaped pieces of metal rebar in a cross formation were positioned over each bucket and anchored in the soil.

All traps were opened on June 22nd 2006, and closed and dismantled on August 15th 2006. As a result, each pitfall was active for 55 days and each lake was visited every other day (2 lakes surveyed daily), from 0800 – 1200. This resulted in 20 trapping periods. When I visited a pitfall array trap, I looked for amphibians along the fence, in each bucket, and 2 m in front of the fence (lake-side). Data collection on adult and YOY amphibians followed procedures described above. I released animals on the upland side of the fence to reduce the likelihood of recapture.

### 3.3 Data Analysis

I used graphics to perform preliminary inspections of patterns in my field data across treatments, lakes, and time periods. Final analyses did not always include all 3 treatments (stocked, unstocked and fishless). To assess the effect of trout stocking on amphibians, I recognized 2 main treatment categories for analysis, stocked (n = 5 lakes) and unstocked (n = 6 lakes). The fishless lake was not included in the latter treatment when assessing the effects of trout stocking on amphibian populations. I performed another set of analyses to assess effects of the presence of fish (native or stocked). Here I also recognized 2 treatments, fish-bearing (n = 11 lakes) and fishless (n = 1 lake).

*Limnological characteristics*

For environmental parameters that could affect amphibian populations, I used mean values for each year in analyses that compared treatments. To test if there was a difference between stocked and unstocked lakes, a 2-way ANOVA was performed with treatment and year (2005, 2006, and 2007) as fixed factors. A Comparison of a Single Observation with the Mean of a Sample test was used to determine if the fishless lake differed in its environmental features from the 11 fish-bearing lakes, in both 2006 and 2007. Values for 2005 were not included because the fishless lake was not sampled that year.

*Call and egg mass surveys*

Call surveys concentrated on adult male wood frogs because they occurred in much higher numbers at study lakes than western toads and boreal chorus frogs. Also, because the duration of wood frog breeding was short (20 d), breeding activities could be surveyed from beginning to end, without interfering with other data collection. For each wood frog survey period, I averaged all chorus Ranks for each lake. Based on lake means, Kruskal Wallis tests was used to determine if there was a difference in calling activity between stocked and unstocked lakes and between sampling periods. To compare female breeding activity, a Mann-Whitney test compared number of egg masses seen on stocked versus unstocked lakes. Call surveys were not conducted on the fishless lake.

*Transect surveys: relative abundance*

I analyzed 3 years (11 lakes in 2005 and 2006, and 10 lakes in 2007) of transect data to compare separate relative abundances (by generating a catch-per-unit-effort: CPUE) of adult and YOY wood frogs, western toads, and boreal chorus frogs between stocked and unstocked lakes. For each transect surveyed for 20 minutes with 1 surveyor (2005), or 10 minutes with 2 surveyors (2006 and 2007), I calculated CPUE (frogs/hr) for each transect surveyed by using all animals of a species seen or caught. For each sampling date on a lake, I calculated the mean CPUE across the 2 - 6 transects surveyed. For analyses, I used mean lake CPUEs for surveys conducted from July 16$^{th}$ – August 15$^{th}$ (6 surveys in 2005, 8 surveys in 2006, and 9 surveys in 2007) so that I could compare CPUEs during the same time period across all 3 years. Relative abundance data was square-root transformed to normalize data. For each species and size class with sufficient data, I conducted a split-plot ANOVA on CPUEs. Year and treatment were fixed factors and

lake was a random variable. When a year or treatment effect was detected, nested ANOVA and Tukey post hoc tests were performed to determine which lakes differed in amphibian abundance. Lakes are of importance because their variability may be driving observed differences in amphibian responses within and between treatments. Relative abundances from the fishless lake were not included in split-plot and associated nested ANOVA analyses.

At the onset of this study in June 2005, Ironside Lake was stocked and subsequently aerated during winter months to promote trout survival. Previously to the 2005 stocking, Ironside Lake had not held trout since 1987. The 2005 stocking gave me the opportunity to document changes in amphibian populations across 3 years following stocking. For each sampling date on Ironside Lake, I calculated the mean CPUE (frogs/hour) across 2 transects. For analyses, sampling date CPUEs from July 16$^{th}$ – August 15$^{th}$ across all 3 years of the study (6 surveys in 2005, 8 surveys in 2006, and 9 surveys in 2007) was used. On adult and YOY wood frog CPUEs (square-root transformed to correct for non-normality), I conducted a 1-way ANOVA comparing CPUEs among years. When a significant result was obtained, a Tukey post hoc test was performed to determine which years differed.

*Pitfall array traps: relative abundance*

I only analyzed pitfall trapping data for YOY wood frogs because this was the only species and age class that was captured in sufficient numbers. For all 20 sampling periods (July 8$^{th}$ – August 15$^{th}$) per lake, using all 6 YOY wood frog pitfall trap array CPUEs (frog/hr), I calculated mean lake CPUE. Relative abundances were square-root transformed to normalize data. A split-plot ANOVA, with treatment and sampling period as fixed factors and lakes as a random factor, was conducted to determine if trout stocking was having an affect on relative abundance of YOY wood frogs. Adult wood frogs were also found in pitfall traps, however, relative abundance was not calculated because some adults escaped by either jumping out or climbing twigs in buckets (C. Schank, University of Alberta, unpublished data).

For the 4 lakes with both transects and pitfall traps in 2006, I compared the number of YOY wood frogs captured by each method (CPUE: frogs/hr) for the shared sampling period of July 17$^{th}$ to August 17$^{th}$. Wood frog CPUE data from transects surveys and pitfall traps were handled the same way as outlined above. I conducted a Spearman's rho correlation and general linear model regression using matched lake CPUE means of transects and pitfall array traps. Comparing results from transects surveys and pitfall trapping allows me to assess whether these 2 commonly used methods yielded consistent estimates of recruitment to metamorphosis for wood frogs on my study lakes, an important metric for evaluating the effects of stocking.

*Transect surveys and pitfall array trap: size (SUL) of adult and YOY wood frogs*

Adult and YOY wood frog SULs from both transect surveys and pitfall traps were included in analysis to compare stocked and unstocked treatments for each year (11 lakes in 2005 and 2006, and 10 lakes in 2007). For each sampling period during July 16$^{th}$ – August 15$^{th}$ for a lake (6 survey periods in 2005, 8 surveys in 2006, and 9 surveys in

2007) I analyzed mean SUL using all adult wood frogs captured during transects and pitfall array trap searches. In contrast to data used for adult wood frogs, to assess size distributions of YOY wood frogs, I calculated mean SUL by using the first 30 YOY wood frogs captured on each lake. The time it took to collect 30 individuals varied from year to year (2005: July 17$^{th}$ to August 12$^{th}$; 2006: July 8$^{th}$ to August 12$^{th}$; 2007: July 10$^{th}$ to August 16$^{th}$). This was done to assure only recently emerged YOY wood frogs were included in analysis. To assess if trout were affecting the size of adult and YOY wood frogs, I used a split-plot ANOVA, with year and treatment as fixed factors and lake as a random variable. When a year and treatment effect was detected, a nested ANOVA and Tukey post hoc test was conducted to determine which lakes differed with respect to amphibian size. Adult and YOY wood frog SUL measurements from the fishless lake were not included in split-plot and nested ANOVA analyses. Since low numbers of adult and YOY western toads and boreal chorus frogs were obtained on some lakes, size distribution analyses were not carried out for these species.

*Transect surveys: date at metamorphosis*

Because I conduced transect surveys during summer months (June through August) in 2005, 2006, and 2007, I was able to determine the timing of wood frog metamorphosis. Date at metamorphosis was not analyzed for western toad and boreal chorus frog because I encountered them too rarely to determine metamorphosis with any confidence. Young-of-year amphibians have been found to metamorphose in concert to reduce predation (Devito 2003). Therefore, instead of inferring metamorphosis date based on the first lone YOY wood frog found, I took a more conservative approach. For each lake, date at metamorphosis was determined when surveyors found a synchronized emergence of at least 4 YOY wood frogs. This date became the date of metamorphosis for that lake in that year. To determine if trout were affecting wood frog date of metamorphosis, a split-plot ANOVA was carried out with year and treatment as fixed factors and lake as a random variable, with date of metamorphosis as the unit of replication.

*Addressing power issues: stocked and unstocked treatment analyses*

With a sample size of 11 lakes, the power (power = 1 – beta; beta = 0.20 – 20 times of 100, when there is an effect, we will say there is not one) for my split-plot and nested ANOVAs was not enough to detect a difference 80% of the time, at an alpha level of 0.05. I approached the problem of low power in two ways. First, separately for the split-plot ANOVAs and nested ANOVAs discussed above, I combined the probabilities from the independent ANOVAs for each metric, i.e., CPUE, SUL, and date at metamorphosis for adult and YOY wood frogs in a test called Combining Probabilities from Tests of Significance (Sokal and Rohlf 1981). To carry out this analysis, I summed the negative natural logarithm of each of the probabilities and evaluated the $X^2$ value under 4 [number of adult associated datasets (CPUE and Size) multiplied by 2] and 6 [number of YOY associated datasets (CPUE, size, and date at metamorphosis) multiplied by 2] degrees of freedom using this equation, $-2\ln P$. Second, I ran a randomization permutation test with R (v2.6.0) on log-transformed data for adult and YOY relative abundance, size and date at metamorphosis for all 3 years. To do this, I ran general linear mixed models (GLMMs; with lake and year as the random factors) on the original ("real") data for each of the independent measurements (5 GLMMs). I randomly allocated 1 of the 2 treatment types

to all lakes in my 5 datasets (in the same proportions as the treatments were found in the original data), then performed the GLMM test on the random data, and repeated this 1200 times for each dataset. Finally, I compared the main effect coefficients attained from the real data to the distribution of main effect coefficients from the randomized tests. For each dataset, if the real, observed coefficient was outside the 95% confidence interval of the distribution of randomized coefficients then I concluded that stocking had a significant effect on adult or YOY wood frog relative abundance, body size or emergence date.

*Fish-bearing lakes vs. fishless lake*

I wished to determine if the simple presence of fish, whether native or stocked, could be the source of any differences for wood frog population parameters collected during transects surveys. Since the fishless lake was added in 2006, only 2 years of data were used in analyses. Mean lake relative abundance, SUL, and date at metamorphosis metrics were all calculated the same way as outlined in Data Analysis – *Transect surveys*. I conducted a Comparison of a Single Observation with the Mean of a Sample test (Sokal and Rohlf 1981) to compare relative abundances, SUL, and date of metamorphosis of adult and YOY wood frogs at 11 fish-bearing lakes (2006) and 10 fish-bearing lakes (2007), with parameters from the 1 fishless lake, Dog Paw. Operationally, this procedure tests whether the population of wood frogs on the 1 fishless lake is an outlier, different from populations on the other lakes. The underlying assumption in interpreting the outcome of the test is that Dog Paw is representative of other fishless lakes in the boreal foothills.

*Statistical programs and post hoc tests*

I used SPSS 15 and R version 2.6.0 for data analysis, and SPSS 15 to generate graphics. When a significant result was found for lakes or years, I used a Tukey HSD post hoc test to determine which means differed significantly from each other.

## 4. Results

### 4.1 Limnological Characteristics

Using mean values of Chl-a and TP from 2005-2007 environmental variables (Table 4), and a nutrient index from Carlson (1977), I classified the study lakes to be oligo-mesotrophic to meso-eutrophic. For TN, TP, and Chl-a environmental parameters, there were significant treatment effects (Table 6); these 3 parameters were all found to be higher in the unstocked lakes than in stocked lakes. Thus, unstocked lakes can be considered more productive than stocked lakes. Summer shallow temperatures and DO values did not differ between stocked and unstocked lakes, but varied from lake to lake, or year to year. pH was significantly higher in stocked than in unstocked lakes (Table 6).

When comparing the fish-bearing treatment to the fishless lake, in 2006, there was a significant difference for TP, DO, and pH, and in 2007, there was a significant difference for every parameter (Table 6). Shallow temperature, TN, TP, and Chl-a were all higher

in the fishless lake compared to fish-bearing lakes. Dissolved oxygen and pH were lower in the fishless lakes then the fish-bearing lakes.

### 4.2 Amphibian Assemblages

Three species of anurans were encountered on the study lakes: wood frog, western toad, and boreal chorus frog (Table 7). The current range of the long-toed salamander and the historic range of the northern leopard frog encompass the study area, but neither species was detected. Of the 3 species, the wood frog was the most abundant amphibian on all lakes and the most consistently encountered.

In 2006, all 3 anuran species were found calling on or around all of the study lakes surveyed (5 stocked and 6 unstocked lakes). Wood frogs and western toads were found calling on all lakes. Boreal chorus frogs were found calling on 73 % of the lakes. On the other 27 % of lakes, boreal chorus frogs were calling in wetlands connected to the lake (areas inundated with lake water, with depths from 30 - 100 cm) or wetlands that were not connected but were within 50 m from lake shorelines.

### 4.3 Call Surveys and Egg Mass Searches

During nightly call surveys in 2006, wood frog call Ranks were assigned to all point count sites. During the 3 wood frog call survey periods on the 11 lakes, I performed 120 point counts and heard 71 groups of males calling and surveyed 63 sites where there was no calling activity (Table 5). For each sampling period, the total number of groups of calling males heard was as follows: survey period 1 = 25, period 2 = 34, and period 3 =12 (Appendix B). The same areas were visited during each survey period, but between period 2 and 3, call Ranks generally declined (i.e., Rank 3 sites became a Rank 2). Most lakes (Ironside, Mitchell, Birch, Gun Range, Fiesta, Picard, and Teal) displayed low mean calling Ranks, while several (Strubel, Yellowhead, Dog Leg, and Gas Plant) displayed high mean Ranks, regardless of treatment (Figure 1).

The mean calling Rank (as a proxy of relative male wood frog abundance) did not differ between stocked and unstocked treatments (Kruskal-Wallis, $\chi^2 = 1.8$, df = 1, P=0.184; Figure 1). However, there was a significant difference in call Rank between sampling periods for all lakes combined (Kruskal-Wallis, $\chi^2=6.4$, df = 2, P = 0.042; Figure 2). Sampling period 3 was significantly lower than periods 1 and 2.

Throughout the 3 call survey periods, I found a total of 640 wood frog egg masses distributed across all study lakes (stocked treatment = 152 egg mass and unstocked treatment = 488 egg masses; Table 8). Egg mass numbers varied between treatments and among survey periods. During most searches, no egg masses were found. I found a total of 13 or fewer egg masses (including several lakes with no egg masses) in 8 of 11 lakes, and in the other 3 lakes the maximum number of egg masses recorded ranged from 107 to 212.

During the first sampling period I found a total of 368 egg masses (stocked lakes = 39, unstocked lakes = 329). During the second sampling period I saw 262 masses (stocked

lakes = 107, unstocked = 155), and in the third I saw 10 masses (stocked lakes = 6, unstocked lakes = 4; Table 8). However, from survey period to survey period, I could not determine if differences in egg mass numbers reflected hatching success or failure, predation, or additional deposition of egg masses. Therefore, only egg masses found during the first sampling period were used in a Mann-Whitney analysis comparing stocked and unstocked lakes. Egg mass counts indicated that female wood frog oviposition patterns did not differ between stocked and unstocked treatments (Mann-Whitney, U=12.5, P = 0.662). Egg masses found during the first survey period at Yellowhead and Dog Leg Lakes all came from call Rank 3 locations. At Birch Lake, 12 egg masses were found at a call Rank 3 location and 1 mass at a call Rank 2 location. Egg masses found at Gas Plant Lake were all found at call Rank 2 locations.

### 4.4 Overview: Transect Surveys and Pitfall Trapping

Each year the number of lakes sampled and number of survey periods differed (see Methods). In 2005, a total of 1,139 individual amphibians (adult and YOY combined) were seen during transect surveys (985 wood frogs, 94 boreal chorus frogs, 60 western toads). In 2006 transect surveys, a total of 2,921 individual were seen (2,103 wood frogs, 293 boreal chorus frogs, 525 western toads). In 2007, 2,083 individuals were seen (1,735 wood frogs, 164 boreal chorus frogs, 184 western toads). As reflected by these totals, in all 3 years adult and YOY wood frogs were relatively abundant compared to the other 2 amphibian species. During transect sampling, adult and YOY boreal chorus frogs and western toads were only encountered on a subset of lakes in each year.

During transect surveys, amphibian capture rates varied. Teams of 1 (2005) or 2 (2006 and 2007) surveyors captured 29.8, 63.9, and 60.3 % of animals observed in 2005, 2006, and 2007, respectively. Based on both treatments combined there was no difference in the number of male versus female wood frogs captured in any of the 3 years (2005: $t_{10}$ = 1.018, P = 0.333; 2006: $t_{10}$= 1.047, P = 0.320; 2007: $t_9$ = 0.001, P = 0.999)

In 2006, 24 pitfall array traps (6 pitfall array traps on each of 4 lakes: active for 55 days), captured a total of 1,065 adult and YOY amphibians (697 wood frogs, 33 boreal chorus frogs, 335 western toads). Adult and YOY wood frogs were trapped on 4 lakes, boreal chorus frogs on 4 lakes (adults on 4 lakes and YOY on 1 lake), and western toad on 4 lakes (adult on 4 lakes and YOY on 3 lakes; Appendix C).

Over the course of the study, all 3 amphibian species were caught in both transect and pitfall traps. In 2006, adult and YOY wood frogs were found with both methods. However, at lakes where adult and YOY boreal chorus frogs and western toads were found in pitfall traps, they were not always found on transect surveys (Appendix C). Therefore, using different sampling methods could offer a way to capture more amphibians and to detect less abundant species.

### 4.5 Transect Surveys: Relative Abundance – Catch-per-unit-effort (CPUE)

*Wood frog*

Relative abundance of adult and YOY wood frogs, as measured by visual transects, did not differ between treatments (Table 9; Figures 3 and 4). For adult wood frogs, but not YOY, there was a significant year effect. In 2007, more adult wood frogs were encountered on transects than in 2005 and 2006. There was no interaction between year and treatment for either age class; however, there was a significant 3-way interaction (treatment, year, and lake) for age classes, i.e., relative abundance varied on any given lake from year to year, and high or low relative abundance could be seen with equal likelihood on stocked or unstocked lakes.

To examine patterns of relative abundance of adult wood frogs among lakes and treatments, I conducted nested ANOVAs for each year (Table 9). For all 3 years, there was a significant interaction between lake and treatment. A Tukey post hoc test was performed to identify which lakes differed from each other. In 2005, 1 stocked lake, Strubel, supported significantly lower abundances of adult wood frogs than 1 stocked lake (Yellowhead) and 1 unstocked lake (Gun Range; Figure 3). In 2006, stocked Yellowhead Lake had significantly higher abundances than 2 stocked lakes (Mitchell and Strubel) and 2 unstocked lakes (Fiesta and Teal). Also in 2006, 2 unstocked lakes differed significantly from each other; Gas Plant Lake had higher abundances compared to Teal Lake. In 2007, abundances of adult wood frogs were significantly higher on stocked Ironside Lake compared to stocked Strubel Lake and 2 unstocked lakes (Gun Range and Gas Plant).

Nested ANOVAs documented a significant interaction between lakes and treatments for relative abundances of YOY wood frogs in 2005 and 2007 (Table 9; Figure 4). A Tukey post hoc test showed that in 2005 Yellowhead Lake had significantly higher abundances of YOY than the other 4 stocked lakes and Fiesta Lake. In 2007, abundances of YOY wood frogs were higher at Mitchell Lake than 2 other stocked lakes (Ironside and Birch).

*Western toad*

Results for split-plot ANOVAs comparing relative abundance of adult and YOY western toad are reported in Table 9. Similar to wood frogs, relative abundance of adult and YOY western toads, as measured by visual transects, did not differ between treatments, among years, and there was no interaction between treatment and year (Figures 5 and 6). However, for both age classes there was a significant 3-way interaction.

Examining inter-lake differences with nested ANOVAs for adult western toad relative abundances, a significant lake by treatment interaction was seen in 2005 and 2007 (Table 9). Tukey post hoc tests indicated that in 2005 stocked Yellowhead Lake had significantly higher abundances of adult toads than stocked Mitchell Lake and 2 unstocked lakes (Gun Range and Picard). In 2007, Yellowhead Lake also had significantly higher relative abundances than 3 stocked lakes (Ironside, Mitchell, and Birch), and 2 unstocked lakes (Gun Range and Picard; Figure 5). Because YOY western toads were rarely encountered at most lakes, I did not perform nested ANOVAs for this

age class. As was true of adult toads, Yellowhead Lake was the only site where I consistently encountered large numbers of YOY toads (Figure 6).

*Boreal chorus frog*

Unlike wood frogs and western toads, relative abundances of adult boreal chorus frogs were significantly higher at unstocked lakes than stocked lakes (Table 9; Figure 7). This was the only case where my prediction of lower abundances of amphibians on stocked lakes was supported. The pattern did not differ significantly among years, and there was no year by treatment interaction. There was a significant 3-way interaction for abundances of adults, which was the only significant pattern for YOY boreal chorus frog abundances. YOY were rarely encountered in visual transects and not found at most lakes in any given year (Figure 8).

A nested ANOVA performed on adult boreal chorus frog relative abundances for each year indicated a lake by treatment interaction in 2005 and 2006 (Table 9). A Tukey post hoc test revealed that in 2005, unstocked Teal Lake, had significantly higher abundances than 4 stocked lakes (Ironside, Mitchell, Yellowhead, and Birch), and 4 unstocked lakes (Dog Leg, Fiesta, Picard and Gas Plant). In 2006, unstocked Fiesta Lake, had significantly higher relative abundances than all 5 stocked lakes and 3 unstocked lakes (Gun Range, Picard, Gas Plant; Figure 8). Because YOY boreal chorus frogs were rarely encountered at most lakes, I did not perform nested ANOVAs for this age class.

### 4.6 Pitfall Array Trapping: Relative abundance – Catch-per-unit-effort (CPUE)

The average time elapsing between checks of pitfall array traps was 50.4 hours. The total number of adult wood frogs found in pitfall array traps was low and did not vary greatly among lakes (58 - 75 individuals). More male wood frogs were captured than female wood frogs, but the difference in abundance was not significant.

On all lakes, pitfall traps were effective in capturing YOY wood frog. However, number of YOY wood frogs captured varied (6 - 263 individuals) from lake to lake. Boreal chorus frog YOY were not found in any of the 24 pitfall array traps. Western toad YOY were not found at pitfall traps on Birch Lake (stocked), but they were captured on the other 3 lakes (2-120 individuals; Appendix D).

I used a split-plot ANOVA to compare YOY wood frog pitfall CPUE between stocked and unstocked lakes and among sampling periods. There was a significant difference between stocked and unstocked lakes ($F_{1,27} = 13.748$; $P = 0.037$, power = 0.1814) with more frogs caught on stocked lakes. Sampling periods were marginally different ($F_{1,27} = 2.722$; $P = 0.072$), representing a possible seasonal pattern. Mid to late July represented peak wood frog emergence. There was a significant date by treatment interaction ($F_{1,27}=3.5851$; $P = 0.03961$) and 3-way interaction ($F_{2,27}=3.358$; $P=.001$). A nested ANOVA showed a significant difference among lakes ($F_{1,2} = 9.5323$; $P = 0.0003$). A Tukey post hoc test showed that YOY wood frog relative abundance was significantly higher at stocked Birch Lake than at stocked Yellowhead Lake and unstocked Dog Leg Lake (Figure 9).

To compare transect surveys and pitfall trapping as methods of measuring relative abundance of YOY wood frogs, I calculated a Spearman's rho correlation for matched mean CPUE (individuals per hour) from visual transects versus pitfall traps for 5 time periods (between July 17 and August 17) for the 4 lakes where I employed both techniques (Figure 10). Results from the 2 methods were not correlated (Spearman's rho: $r = 0.047$, $df = 16$, $P = 0.862$, $B = 420$). When relative abundance from transects was high for a particular sampling date for a lake, relative abundances from trapping tended to be low with the exception of Birch Lake. When the second sampling period was removed from Birch Lake (which has an outlier due to very high numbers of YOY encountered via both methods) the regression slope actually became negative ($B = -0.221$), but the correlation coefficient statistic remained small and was not significant (Spearman's rho: $r = -0.158$, $df = 15$, $P = 0.575$).

### 4.7 Body Size

*Adult wood frogs*

Only the wood frog was abundant enough to make meaningful comparisons of body size of adult animals from stocked and unstocked lakes. I predicted that if wood frogs metamorphose at a smaller size to avoid predation they will never "catch up" to attain a large body size. Thus, I expect to see smaller adult anurans at stocked lakes. SUL measurements for adults were obtained through both transect (2005, 2006, and 2007) and pitfall array traps (2006) because I assumed all animals come from the same population. Size measurements for males and females were combined because no difference was seen in male and female numbers (see above, *Transect survey and pitfall trapping*).

Results of split-plot ANOVA showed that adult wood frog body size did not differ between stocked and unstocked lakes, but there was a year effect (Table 10; Figure 11). Adult wood frogs were larger in 2005 than in 2006 and 2007. There were no 2 or 3-way interactions. Nested ANOVA indicated a significant interaction between lake and treatment for 2006 and 2007. Using a Tukey post hoc test, in 2006 adult wood frogs on a stocked Mitchell Lake were found to be significantly larger than frogs on 2 unstocked lakes (Teal and Gas Plant). However, a Tukey post hoc test did not document significant differences among lakes in 2007. See Appendix E for SUL means, standard error, and sample sizes.

I wished to determine if seasonal variation affected adult wood frog body size. For example, if there was a large recruitment of metamorphs on unstocked lakes in summer 2005 and I captured a large number of these animals in June 2006, my measure of adult body size on unstocked lakes would be biased by the frequent occurrence of small, 1-year old individuals. Since 2006 was the only year where adult wood frog SUL measurements from transect sampling were recorded during the full suite of summer months (June 1$^{st}$ - August 28$^{th}$), adult wood frog size was assessed to see if SUL varied across months and treatments. For every date a lake was sampled (5 survey periods in June and 4 survey periods in July and August), the mean SUL of all adult wood frogs caught during all transects were calculated. Then sampling dates were separated into corresponding

calendar months. A split-plot ANOVA indicated that the size of adult wood frogs did not differ between stocked and unstocked treatments ($F_{1,9} = 0.335$; $P = 0.800$) or among months ($F_{1,2} = 0.233$; $P = 0.629$), and there was no treatment by month interaction ($F_{1,2} = 0.050$; $P = 0.952$; Table 10; Figure 12). However, there was a significant treatment by lake interaction (Nested ANOVA: $F_{1,9} = 3.369$; $P = 0.001$; Table 10). A Tukey post hoc test showed adult wood frog size in 2006 varied among lakes, regardless of stocking regime. One stocked lake, Yellowhead had significantly smaller adults compared to 3 stocked lakes (Ironside, Mitchell, and Birch) and unstocked Dog Leg Lake. Another unstocked lake, Gas Plant, had significantly smaller adults compared to 2 stocked lakes (Mitchell and Birch) and 1 unstocked lake, Dog Leg. See Appendix E for means, standard error, and sample sizes.

*YOY wood frogs*

I predicted that YOY anurans would be smaller at metamorphosis in stocked lakes versus unstocked lakes. Only YOY wood frog SUL was analyzed because YOY boreal chorus frog and western toads were not captured in sufficient numbers across treatments. The range of wood frog YOY caught on a single lake for a given day during metamorphosis was from 1 - 108 individuals. The actual number measured ranged from 2 - 30 individuals per lake and the time it took to acquire 30 individuals varied within and across years (Appendix E). For example, it took 1 day on Birch Lake (10 July 2006), and 29 days on Mitchell (July 18$^{th}$ – August 16$^{th}$ 2007) to capture 30 YOY. In 2005 and 2007, only transect captures were used. In 2006, the first 30 YOY wood frogs captured on transects or pitfall array traps were used in analyses. Mean size of newly metamorphosed YOY wood frogs did not differ between stocked and unstocked lakes (Table 10; Figure 13), and unlike adults, the body size of YOY wood frogs did not differ significantly among years.

Nested ANOVAs indicated that there was a significant lake by treatment interaction for all 3 years (Table 10). When looking at lake by treatment interactions, a Tukey post hoc test uncovered considerable variation between lakes within years. In 2005, wood frogs at a stocked lake, Birch, were smaller than wood frogs on unstocked Picard Lake. Wood frogs at unstocked Gas Plant Lake were smaller than 2 stocked lakes (Ironside and Yellowhead) and 4 unstocked lakes (Gun Range, Dog Leg, Fiesta, and Picard). In 2006, stocked Birch had smaller wood frogs than 3 stocked lakes (Ironside, Mitchell, and Strubel) and 3 unstocked lakes (Gun Range, Picard, and Teal). Stocked Yellowhead Lake had smaller YOY wood frogs than 2 stocked lakes (Ironside and Strubel) and 3 unstocked lakes (Gun Range, Picard and Gun Range). Unstocked Dog Leg and Gas Plant Lake had smaller YOY wood frogs than 2 stocked lakes (Ironside and Strubel) and 1 unstocked lake, Picard. In 2007, stocked Birch Lake had smaller YOY wood frogs than stocked Ironside Lake and 2 unstocked lakes (Gun Range and Fiesta). Stocked Mitchell Lake had larger YOY wood frogs than stocked Ironside, Strubel and Yellowhead Lakes, and unstocked Gas Plant Lake. Stocked Strubel had smaller YOY wood frogs from stocked Ironside Lake and unstocked Fiesta Lake. Stocked Yellowhead Lake had smaller YOY wood frogs compared to stocked Mitchell Lake and 2 unstocked lakes (Gun Range and Fiesta). All SUL means, standard error, and sample sizes are found in Appendix E.

### 4.8 Timing of Wood Frog Metamorphosis

As outlined above, timing of metamorphosis was determined when at least 4 YOY wood frogs were found emerging simultaneously from a single stretch of shoreline, represented by a single transect. Using a single transect, instead of the entire lake shoreline, allows one to see localized group emergent events, instead of various single YOY emergent events around the lake. However, each year there were a few lakes (2005 = 2, 2006 = 2, 2007 = 2 lakes) where the number of synchronously emerging YOY wood frogs did not reach 4 individuals. In these cases the date at which I saw the largest number of YOY emerging became the 1st day of metamorphosis. Calendar metamorphosis dates, which ranged from July 06th to August 16th, were converted to Julian day.

Date of metamorphosis for wood frogs varied little from lake to lake and year to year (Figure 14). Split-plot ANOVA indicated no statistical difference between treatments ($F_{1,9} = 0.189$; $P = 0.674$), years ($F_{2,17} = 0.732$; $P = 0.495$) and no year by treatment interaction ($F_{2,17} = 0.732$; $P = 0.489$) or lake by treatment interaction ($F_{2,9} = 1.302$; $P = 0.305$). In 2006 there was a trend towards an earlier metamorphosis date in unstocked lakes compared to stocked lakes, but in 2005 and 2007 mean metamorphosis date on stocked and unstocked lakes were virtually identical. Thus my prediction that time to metamorphosis on stocked lakes would be shorter than on unstocked lakes was not supported.

### 4.9 Additional Analyses Comparing Stocked and Unstocked Lakes

Most of my results indicate that amphibian populations, more specifically wood frog populations, do not respond to trout stocking. To compensate for low power for many of my tests, I tested for effects of stocking and differences between stocked and unstocked lakes using 3 additional approaches.

Ironside Lake was stocked on June 2nd 2005 for the first time in 18 years, and gave me an opportunity to track amphibian population responses for 3 years after stocking. Relative abundances of adult and YOY wood frogs, based on transect surveys, differed significantly among years (1-way ANOVAs; adult: $F_{2,26} = 8.12$; $P = 0.002$; and YOY: $F_{2,20} = 7.82$; $P = 0.004$; Figure 15). Tukey post hoc test showed that relative abundances of wood frogs were similar in 2005 and 2006, but in 2007 relative abundances of both age classes increased drastically, causing significant differences between 2007 and the 2 previous years. Thus to date there is no evidence of a negative effect of trout stocking on adult abundance or recruitment of YOY wood frogs on Ironside Lake. In fact, there may actually be a positive effect.

On Ironside Lake, adult wood frog size differed significantly across years (1-way ANOVA: $F_{2,38} = 5.228$; $P = 0.01$). Tukey test showed adult wood frogs were larger in 2005 than in 2006, and 2007 (Figure 16). Young-of-year wood frog SUL did not differ among years (1-way ANOVA: $F_{2,33} = 0.559$; $P = 0.577$). However, in 2005 and 2006 only 2 YOY individuals were captured, whereas, 30 YOY wood frogs were caught in 2007 (Appendix E).

A second approach to determine if there was an effect of stocking on wood frog populations was to perform a Combining Probabilities from Tests of Significance (Sokal and Rohlf 1981) analyses on wood frog transect data. This test was performed separately on results of previously reported split-plot and nested ANOVAs. Tests were based on P-values from ANOVAs of 1) relative abundance and body size of adult wood frogs or 2) relative abundance, body size, and date of metamorphosis of YOY wood frogs. Degrees of freedom (df) were calculated by multiplying the number of P-values by 2. Using split-plot ANOVA P-values, a significant stocking effects were not detected for adult wood frogs ($X^2$=1.308, df = 4) or YOY wood frogs ($X^2$ = 2.172, df = 6). Nested ANOVA P-values for each year showed no significant effects of stocking on adult wood frogs (2005: $X^2$ = 6.427, df = 4; 2006: $X^2$ = 8.691, df = 4; 2007; $X^2$ = 4.530, df = 4) and YOY wood frogs (2005; $X^2$ = 6.221, df = 6; 2006: $X^2$ = 7.657, df = 6; 2007; $X^2$ = 5.630, df = 6) for any of the 3 years.

The third test was done using R, version 2.6.0. and tested whether the lack of difference I detected between stocked and unstocked lakes was due to chance alone. Using R, I ran a permutation randomization analysis to test for differences in relative abundance and size of adult wood frogs and relative abundance, size and date at metamorphosis for YOY wood frogs in stocked and unstocked lakes from visual transect data. For each sampling date a lake was surveyed, adult and YOY mean CPUE (all transect surveys) and SUL (all transect surveys and pitfall traps) were calculated. This test addresses the question: How likely is it that, if the null hypothesis was true (i.e., stocking has no effect on amphibian population parameters), we would obtain the observed value due to chance alone? If the null hypothesis is rejected, we would conclude that stocking has real effects on amphibians. For each population measurement examined, this test documented that observed differences recorded between the 2 treatments are not different from random variation (adult CPUE: P = 0.71; YOY CPUE: P = 0.14; adult SUL: P = 0.77; YOY SUL: P = 0.53; YOY date of metamorphosis: P = 0.64). As a result, the differences that I saw between stocked and unstocked lakes are equivalent to the difference that I would see by chance alone when sampling 2 identical populations; the null hypothesis was not rejected.

### 4.10 Fish-Bearing and Fishless Treatments

Based on the Comparison of a Single Observation with the Mean of a Sample test, for 2006 and 2007, the relative abundance of adult wood frogs was significantly higher at the fishless lake than the lakes with fish, for both years (2006: $t_{10}$ = - 4.033, p = 0.002; 2007: $t_9$ = - 2.981, P = 0.015; Figure 3). The relative abundance of YOY wood frogs was also higher at the fishless lake compared to fish-bearing lakes in 2007 ($t_9$ = -3.332, P = 0.009), but not in 2006 ($t_{10}$ = - 0.551, P = 0.594; Figure 4). Adult wood frogs were significantly larger at the fishless lake in both 2006 ($t_{10}$ = - 2.728, P = 0.021) and 2007 ($t_9$ = - 3.341, P = 0.007; Figure 10). YOY wood frogs were larger on the fishless lake than the fish-bearing lakes in 2006 ($t_{10}$ = - 2.262, P = 0.047), but not in 2007 ($t_9$ = - 0.902, P = 0.388; Figure 13). Date of metamorphosis for wood frogs did not differ between the lakes with fish and the fishless lake in either 2006 ($t_{10}$ = - 0.8984, P = 0.195) or 2007 ($t_9$ = - 0.1904, P = 0.4266; Figure 14).

Using 2006 transect data from all 11 lakes with fish (5 stocked and 6 unstocked lakes) and the 1 fishless lake, a Comparison of a Single Observation with the Mean of a Sample tests was performed for June, July, and August, to see if there was an effect of fish presence on adult wood frog size shortly after the breeding season (June) and as the summer progressed. Size data were calculated the same way as described earlier, but sampling periods were grouped into months (5 sampling periods in June and 4 sampling periods in both July and August). For each month in 2006 there was a significant effect of fish presence (June: $t_9 = 36.726$, P=0.0001; July: $t_9 = 34.987$, P = 0.0001; August: $t_9 = 32.250$, P = 0.0001). In June, adult wood frogs were larger on fish-bearing lakes (N = 115) compared to fishless lake (N = 47). In July and August, adult wood frogs were larger on the fishless lake (July, N = 7: August, N = 2) than the fish-bearing lakes (July, N = 142: August, N = 79). These results could reflect real effects of fish on adult wood frogs, but the sample size for the fishless lake was small.

## 5. Discussion

### 5.1 Main Findings

To investigate the effects of stocked trout on amphibian populations, I used intensive, repeated surveys of a select number of lakes, rather than an extensive, superficial survey of a large number of lakes. Extensive surveys typically provide seasonal presence/absence snap-shots of an area at a fixed time of day, whereas intensive surveys allow lakes to be visited at different times of the day, throughout the spring and summer. Another positive feature of this approach was that it allowed me to sample a large number of animals. Thus, I could assess the consistency and robustness of various metrics for adult and YOY amphibians (relative abundance, size, and date at metamorphosis) for a given lake. A shortcoming of this intensive survey method is the number of lakes that can be included in a study, which may reduce statistical power and the ability to detect real effects of stocking.

Using this intensive survey method, I documented that 3 anuran species (wood frog, western toad, and boreal chorus frog) co-occur with dense populations of native forage fish in boreal foothill lakes. I found no evidence that the addition of trout to study lakes led to the elimination of amphibian populations, and only adult boreal chorus frog displayed any reduction in numbers. These results contradict with findings from many other fish-amphibian studies (Bradford et al. 1998; Knapp and Matthews 2000; Pilliod and Peterson 2001; Knapp 2005). To showcase the overall result that there is no strong evidence that amphibian populations are affected by trout stocking in boreal foothills lakes, I will review key findings of my study.

Regarding abiotic factors, comparisons of water chemistry indicated that unstocked lakes had higher levels of TN, TP, and Chl-a than stocked lakes. Therefore, lakes chosen for stocking tend to be less productive than unstocked lakes. Stocked lakes with low

production may reduce the risk of summerkill and winterkill events. Enironmental parameters tend to vary from lake to lake, and year to year.

Depending on the amphibian species and age class, patterns varied among years and lakes, regardless of stocking status. Wood frogs and western toads called on all lakes surveyed; mean call Rank for male wood frogs did not differ between stocked and unstocked lakes. Boreal chorus frogs were found calling on 8 of 11 lakes. At the remaining 3 lakes, male boreal chorus frogs called only from adjacent wetlands. Relative abundance data from visual surveys and pitfall trapping yielded different patterns with respect to treatment effects. Based on transect surveys, relative abundances of adult and YOY wood frog and western toad did not differ between treatments. Abundance estimates of adult, but not YOY, boreal chorus frog were significantly higher on unstocked lakes. Pitfall trapping data documented a treatment effect for relative abundances of YOY wood frogs with more YOY captured on stocked lakes. Body size (SUL) of adult wood frogs, from animals captured on transects and in pitfall traps, showed no treatment effect. Young-of-year wood frogs did not differ in size or date at metamorphosis in stocked versus unstocked treatments. After Ironside was stocked for the first time in 18 years, there was no evidence of a trout effect on adult and YOY wood frog CPUE and size post-stocking.

Unlike the general lack of evidence that stocked trout affected amphibian populations, the alternative, that the presence of any fish species affected amphibian populations received support from my study lakes. Relative abundances of adult (2006 and 2007) and YOY (2007) wood frogs were significantly higher on my 1 fishless lake compared to the 11 lakes containing native forage fishes and stocked trout. Adult (2006 and 2007) and YOY (2006) wood frogs tended to be larger on the fishless lake, although wood frog date at metamorphosis did not differ between lakes with fish and without fish. The fact that the amphibian population found at the fishless lake differed from populations from the 11 fish-bearing lakes suggests that the presence or absence of fish was behind these differences. However, more fishless lakes need to be surveyed to conclude with confidence, that native forage fishes negatively affect amphibian populations in boreal foothill lakes even in the absence of introduced trout.

### 5.2 Habitat Features

In most studies examining systems where fish have been stocked, water chemistry data are not reported, however, elevation, lake area (ha), lake depth and substrate usually are documented (Knapp and Matthews 2000; Knapp 2001; Adams et al. 2003). Even though Parker and colleagues (2001) did not address trout and amphibian interactions, they showed that stocked trout extirpated 2 large crustaceans (*Hesperodiaptomus arcticus* and *Daphnia middendorffiana*) from alpine lakes with stocked trout in the Rocky Mountains of Alberta, and provided water chemistry data. I compared water chemistry from alpine lakes with my study lakes. In both ecoregions, mean pH were comparable (alpine = 8.00, boreal foothills = 7.75), while mean alpine lake conductivity values (281 µS/cm) were higher and TN (166 µg/L), and TP (7.1 µg/L) were considerably lower than in boreal foothills lakes (mean values: conductivity = 140.64 uS/cm, TN = 860.74 µg/L, TP =

26.84 µg/L). Systems with high nutrient levels (TN and TP) can have increased productivity, promoting biodiversity, which can lead to ecosystem stability in the face of disturbances such as species introductions (Carpenter et al. 1985; Parker and Schindler 2006).

Elevated oxygen levels from artificial aeration could directly influence distributions, survivorship, and behaviour of larval amphibians (Wassersug and Seibert 1975; McIntyre and McCollum 1999; Babbit et al. 2003), but indirect effects on biota would be more likely to affect amphibian populations in the boreal foothills, than direct effects of aeration. Wood frog, western toad, and boreal chorus frog are all terrestrial hibernators, thus elevated winter oxygen levels in my study lakes would affect these anurans less than species, such as mountain yellow-legged frog that hibernate underwater (Bradford 1983; Lamoureux and Madison 1999). Despite the fact that some study lakes (Ironside and Mitchell) were aerated to promote over-winter survivorship of trout, summer artificial aeration did not occur and stocked and unstocked lakes did not differ in summer oxygen levels.

### 5.3 Trout Diet: What are Trout Eating?

High lake productivity and readily available invertebrates and forage fish found in boreal foothill lakes may decrease the likelihood of trout predation on all amphibian life history stages. In my study lakes, there was no difference in relative abundance (% occurrence) and composition of aquatic invertebrate taxa between stocked and unstocked lakes (L. Nasmith, University of Alberta, personal communication). Similarities in relative abundance (% occurrence) and composition across my study lakes indicated that similar invertebrate assemblages co-occur with stocked trout and native forage fishes. For example, in both stocked and unstocked lakes, the top 5 aquatic invertebrate taxa (order or class) found in my study lakes were: Nematocera, Amphipoda, Gastropoda, Bivalvia, and Ephermeroptera (L. Nasmith, University of Alberta, personal communication). Other studies have focused on mean abundance (benthic invertebrate per $m^2$) and total biomass (mg/m or mg/L) of functional benthic invertebrate groups, and found that invertebrate assemblages generally do not differ in the presence or absence of fish (brown trout: Dahl and Greenberg 1998; Wissinger et al. 2006; large-mouth bass, *Micropterus salmoides*: Blumenshine et al. 2000). However, it has been shown that introduced fish can negatively affect aquatic invertebrate richness (Carpenter and Kitchell 1988; Blumenshine et al. 2000; Knapp et al. 2005). Numerous studies have documented that fish have varying effects on invertebrates, so caution must be taken when extrapolating effects of introduced trout or other sport-fishes on invertebrate assemblages from one study system to another.

All 11 fish-bearing lakes in my study contained native small-bodied fishes, occurring at densities from 592 cyprinids/ha to 17,766 cyprinids/ha, with a mean density of 4,550 cyprinids/ha. Only cyprind densities were calculated because brook stickleback was caught too rarely to estimate populations (L. Nasmith, University of Alberta, personal communication). In 2005, forage fish densities did not differ between stocked and unstocked lakes, but in 2006 stocked-aerated lakes,(Ironside and Mitchell) had the

highest cyprinid densities and unstocked lakes (Gun Range, Dog Leg, Fiesta, Picard, Teal, and Gas Plant) had higher cyprinid densities than stocked lakes that were not aerated (Strubel, Yellowhead, and Birch Lakes; L. Nasmith, University of Alberta, personal communication). Forage fish in my study lakes are abundant enough to provide a readily accessible, high energy food source for introduced trout.

Assessment of diet of trout in my study lakes during 2007 showed that forage fish and aquatic invertebrates occurred in 7.6 % and 79.4 % of stomachs, respectively (J. Hanisch, University of Alberta, personal communication). Even though trout in my study lakes did not affect invertebrate abundance, trout were still found to predominately foraged on aquatic invertebrates, such as Chironomidae, Daphnidae, Odonata (Anisoptera), Amphipoda, and Gastropoda, and to a lesser extent, Corixidae, Zygoptera, Notonectidae, Dytiscidae, and Hirudinea (J. Hanisch, University of Alberta, personal communication). Bradford and colleagues (1998) found that large, mobile, conspicuous aquatic invertebrate taxa (*Daphnia,* Baetidae, Ephemeroptera, Notonectidae, Corixidae, Tricoptera, and Dytiscidae) were rare or absent and taxon richness was reduced in fish-bearing lakes compared to fishless lakes, implying a fish effect on invertebrate assemblages. Large-mouth bass, a large piscivore fish similar to trout in diet (Blumenshine et al. 2000), was found to forage mostly on benthic prey, including Hirudinea and immature Anisoptera, Molluscs, Coleoptera, Trichoptera larva, and Chironomidae (Diptera) in the absence of small-bodied prey fish. Bolger and others (1990) found brown trout living in an upland reservoir with small-bodied fish, Eurasian minnow (*Phoxinus phoxinus*), three-spined stickleback (*Gasterosieus aculeatus*), and stoneloach (*Noemacheilus harbatulus*), preyed mostly on Trichopera larva and pupae and Chironomidae. These studies suggest that large-bodied piscivorous fish do feed on invertebrate taxa found in my study lakes, and that in some systems choose invertebrate prey over vertebrate prey such as forage fish.

Stomach contents of 399 trout indicated that trout in all stocked lakes preyed upon invertebrates and native small-bodied fishes, yet no amphibian remains were ever found (J. Hanisch, University of Alberta, personal communication). It can be assumed that tadpoles and eggs are readily digested due to a predominance of soft tissues that are easily broken down by stomach acid, thus the likelihood of encountering tadpole remains in fish stomachs is low. However, adult and YOY amphibians should be more easily detected. I propose that due to availability and abundance of other prey, and factors affecting trout and amphibian encounter rates (e.g., shoreline development, slope, and macrophyte species and densities), trout are not consuming any life history stage of amphibians in my study lakes. To document preference for other prey or avoidance of amphibians by trout, detailed dietary information would need to be collected, and laboratory based feeding experiments might be required.

### 5.4 Calling Behaviour

Call surveys are widely used to document the distribution of amphibian species across landscapes (Palik et al. 2001; Stevens et al. 2002) and to estimate abundance and levels of reproductive activity at specific locations (Stevens et al. 2002, Stevens and Paszkowski

2004). Traditionally, smaller 0.02 – 6.0 ha wetlands and ponds have been the focus of call surveys (Wells and Taigen 1986; Dyson et al. 1998; Oseen and Wassersug 2002; Stevens and Paszkowski 2004). I performed call surveys on larger water bodies, lakes (3.3 – 28.0 ha). The extensive shorelines of lakes are much more heterogeneous than those of ponds in terms of perimeter, slope, vegetation, and substrate. Because of this, calling and oviposition sites of anurans are likely to have a patchy distribution. Patchy distributions may result from a limited availability of high quality oviposition sites, or a surplus of oviposition sites and lack of large choruses of breeding males and large concentrations of eggs. It is generally believed that most temperate anuran species avoid breeding in lakes because these habitats often contain fish (Kats and Sih 1992; Binkley and Resetarits 2003; Rieger et al. 2004). My study shows that call surveys can be carried out on larger water bodies (i.e., lakes), but results need to be interpreted conservatively because entire shorelines are not surveyed.

In 2006, I used call surveys primarily to determine if the 3 amphibian species present in my study area were indeed breeding on study lakes. Visual encounters of adult amphibians along the shoreline of a water body do not necessarily mean that they breed there; neither does presence of YOY in riparian areas (Stevens et al. 2007). Adding call and egg mass surveys links the occurrence of male courtship and successful breeding to amphibian presence in visual surveys (Stevens and Paszkowski 2004). Of the 3 species, only boreal chorus frog was not found calling on all lakes (3 of 11). On 2 stocked lakes (Mitchell and Strubel) and unstocked Gun Range Lake, boreal chorus frogs called from disconnected nearby shallow wetlands, ca. 0.3 – 0.5 m deep. Wood frogs and western toads called on all lakes and did not seem to be avoiding fish. The observation that boreal chorus frogs did not call on 2 stocked lakes suggests that they may be avoiding lakes with trout.

Unlike boreal chorus frogs and western toads, which seldom achieved Rank 2 and 3 calling indices across the study lakes, wood frogs were commonly heard in Rank 1 through 3 choruses over 20 days of sampling. The range of Ranks recorded allowed this metric to be compared across lakes as a relative measure of breeding activity. Although individual lakes varied considerably in the amount of calling activity, stocked and unstocked lakes did not differ with respect to mean calling Rank. This lack of a stocking effect on calling males was consistent with a lack of a stocking effect on relative abundance of YOY wood frogs.

I attempted to make a direct link between patterns of male calling and egg deposition for wood frogs by searching for egg masses the morning after call surveys. Following procedures in Stevens and Paszkowski (2004), I hoped to translate calling intensity into estimates of the number of breeding males. Since egg searches were largely unsuccessful, likely due to complexity and extent of lake shorelines, no correlations were detected. I was limited in my ability to locate wood frog egg masses in most lakes because of dense emergent vegetation, course woody debris, and in some areas the water was deep and opaque, making it hard to detect the dark round egg masses of wood frogs. Nevertheless, later in 2006 YOY wood frogs were encountered at all lakes, sometimes at high relative abundances (e.g., Birch Lake). Because YOY wood frogs were always

found within meters of the water, and the distance to other water bodies usually exceeded 100 m, I am confident that YOY amphibians came from the study lakes. The presence of YOY wood frogs at all lakes showed egg mass searches were ineffective and not a good measure of amphibian reproductive activity in my study lakes.

### 5.5 Relative Abundances of Amphibians

The intolerance of amphibian species to the presence of native predators of their eggs (Touchon et al. 2006; Gomez-Mestre and Warkentin 2007) or larvae (Bradford et al. 1983; Gillespie 2001; Baber and Babbitt 2003; Mirza et al. 2006; Saglio and Mandrillon 2006), and in some cases adults (Murray and Wirsing 2004; Verburg et al. 2007), has been emphasized by the literature. In these systems, amphibians may seek out water bodies with reduced predation pressure. Temporary water bodies cannot support the long-lived vertebrates that inhabit permanent water bodies (i.e., large- and small-bodied fishes), and although permanent water bodies offer more stable environments, they also contain a greater diversity of predatory invertebrates compared to ephemeral waters (Wellborn et al. 1996). Therefore, amphibian species richness may be higher in temporary water bodies (Hecnar and M'Closkey 1997). However, in temporary as well as permanent water bodies, if a predator is introduced and becomes established, naïve prey populations may decline or be extirpated (Cox and Lima 2006).

An abundance of alternative prey might buffer adult and larval amphibians from predation by trout. Trout are generalists, but are known to focus their efforts on prey sizes that are more abundant (Rincón and Lobón-Cerviá 1999) or larger (Luecke 1990; Carlisle and Hawkins 1998). Since no amphibian life history stages were found in trout stomachs it is possible that amphibians in my study lakes evolved antipredator behaviours towards native forage fish, which they later transferred to introduced trout. Kats and Ferrer (2003) proposed that true naiveté toward a new predator does not exist in prey that have had some exposure to similar taxa (i.e., other fishes).

In the eastern portion of its range, the wood frog is a species that is generally considered to be relegated to smaller, ephemeral water bodies, and exhibits a sensitivity to fish predation as inferred from relationships between fish occurrence and pond hydroperiod (Chivers and Mirza 2001; Babbitt et al. 2003; Rubbo and Kiesecter 2005). However, wood frogs in Alberta commonly breed not only in lakes that contain minnows and sticklebacks, but also in lakes (> 10 ha) with large native piscivores, such as northern pike (*Esox lucius*) and yellow perch (*Perca flaviscens*) (Eaton et al. 2005). The species obviously has the capacity to co-occur with fishes, albeit often at lower densities than in fishless systems (see below).

Due to the predatory behaviour of trout, larval amphibians are probably more at risk than egg and adult life history stages. This is verified in the literature, for majority of egg mortality is caused by aquatic invertebrates (Formanowicz and Brodie 1982; Touchon et al. 2006; Gomez-Mestre and Warkentin 2007), and trout generally feed on tadpoles (Gillespie 2001; Verburg et al. 2007). My study documented abundances of adult and YOY amphibians, not tadpoles. Berven (1990) demonstrated, however, that wood frog

populations are regulated by events at early life history stages: adult wood frog numbers are directly linked with juvenile recruitment which is linked with larval recruitment. Thus, all life history stages can be affected by aquatic predation pressures. I believe this pattern extends to body size; smaller larvae potentially become small metamorphs and adults. By looking at adult relative abundance and size, and YOY relative abundance, size and date at metamorphosis, I can project what happened at the larval life history stage and extrapolate effects of introduced trout.

The most obvious manifestation of the effects of vertebrate predators is the absence or reduction in abundance of some amphibian species and general decrease in amphibian species richness from sites where certain native predators are present (Hecnar and M'Closkey 1997; Murray and Wirsing 2004; Egan and Paton 2004) or the extinction of amphibian populations when novel predators enter a system (fish: Fellers and Drost 1993; Murray and Wirsing 2004; Knapp 2005; crayfish: Cruz et al. 2006). Fellers and Drost (1993) documented that over a 15 year period, cascade frogs (*Rana cascadae*) were extirpated from Lassen Volcanic National Park, California, USA, when they only found 2 individuals at 1 of 50 ponds. They hypothesized that introduced brook and rainbow trout were the causes of these declines. Through a correlative study, Egan and Paton (2004) found that wood frog and spotted salamander (*Ambystoma maculatum*) egg mass numbers were reduced in ponds with native fish, suggesting that these species avoid fish or that fish prey on eggs. In support of the first mechanism, Murray and Wirsing (2004) found that Columbia spotted frogs (*Rana luteiventris*) used chemical cues to avoid areas where native garter snakes (*Thamnophis elegans*) occurred.

I found no evidence that stocking trout had extirpated amphibian populations as all amphibian species detected in my study were observed at all lakes despite the fact that Mitchell and Strubel Lake have been stocked for more than 50 years. It is possible that abundances of amphibians have declined due to stocking. With the stocking of Ironside Lake in June 2005 after the absence of trout for 18 years, I was able to document that relative abundance and body size of adult and YOY wood frogs did not decline for 3 years following trout introductions. In fact, relative abundances may have been increasing. One possibility could be that trout are indirectly affecting amphibian relative abundances by reducing predation or competition from predatory invertebrates and forage fish. The size of adult wood frogs did decrease, which could be interpreted as size selective mortality of older frogs or a result of reduced growth due to higher densities of larvae or metamorphs.

Factors other than predation and environmental parameters can affect amphibian abundances. For example, in 2007 transect surveys on Mitchell Lake produced fewer adults per hour and more YOY per hour than on other stocked lakes. This may be an artifact of human use. Half of the shoreline is accessible to the public and 100 m of shoreline is actually a camping area. People camp and fish there and it was observed that children search for capture amphibians (C. Schank, University of Alberta, personal observations). Due to the larger size of adults versus YOY frogs, adults may have a greater risk of being captured, ultimately affecting numbers of adult wood frogs found at the lake.

Compared to wood frogs, western toads occur on fewer lakes and ponds in western Alberta and tend to be less numerous (Stevens et al. 2007). Toads on my study lakes were no exception, but there was no link between the relative abundance of adults and stocking. Likewise, although YOY were only observed on 7 lakes (4 stocked and 3 unstocked), abundances were comparable on stocked and unstocked lakes. The exception was stocked Yellowhead Lake, which had considerably higher relative abundances year after year for YOY, and usually for adult toads as well. High relative abundances on Yellowhead Lake may be a result of muddy shallow shorelines, which may be an important habitat feature (Devito 2003). Furthermore, tadpoles and adult Bufonidae are viewed as fairly tolerant of fish predation, and breeding populations can co-exist with a variety of fish species (Denton and Beebee 1997; Crossland 2001; Eaton 2005) including trout (Welsh 2006). Tolerance is linked to skin toxins that are noxious to many vertebrates, making them unpalatable to a large suite of predators. This unpalatable toxin may contribute to the fact that both adult and YOY western toads in boreal foothills lakes can co-occur with both large- and small-bodied fish.

Adult boreal chorus frog was the only species and age class that occurred at significantly lower relative abundances on stocked versus unstocked lakes. The fact that YOY were rarely seen anywhere may be why there was no treatment effect for relative abundances. For example, in 2006 I did not see a single YOY boreal chorus frog on transects, even though call surveys detected adults calling on lakes. Boreal chorus frogs were hard to detect during visual searches because of their small size, cryptic colouration and inconspicuous movements. I encountered one-tenth the number of chorus frogs as wood frogs. Observed patterns in adult abundance are consistent with reports for other members of the genus *Pseudacris*. Bull and Marx (2002) documented that the Pacific tree frog (*P. regilla*) exhibited decreased populations in the presence of brook trout but not rainbow trout. Skelly (1995 and 1996) found that the western chorus frog (*P. triseriata*) preferred to reproduce in shallow, ephemeral ponds over lakes. I found that on 3 of my study lakes, boreal chorus frogs were not calling from the lakes themselves but from connected, adjacent wetlands (see above). Detectability may have been a factor, but boreal chorus frogs did appear to be avoiding contact with fishes, resulting in a negative response to stocking.

### 5.6 Relative Abundance as Measured by Pitfall Array Trapping and Differences between Sampling Methods

Measurement of the relative abundance of amphibians is the most straight-forward way to assess the impact of predators on populations, yet different methods for measuring abundance can yield different patterns. For YOY wood frog, visual transects indicated no difference in abundance between stocked and unstocked lakes, whereas pitfall trapping did. However, contrary to expectations, trapping showed a higher relative abundance of YOY wood frog on stocked lakes. There was no clear correlations between CPUE for transect surveys and pitfall trapping for matched sampling periods in 2006; in fact, the trend was negative.

The fact that I found a weak inverse relationship between numbers of YOY wood frogs between transects and pitfall traps strongly suggested that the two methods are measuring different aspects of population demography or behaviour. The pattern that I saw for pitfall trapping (higher abundance of YOY on stocked lakes) was certainly influenced by the fact that I only had the resources to trap on 4 of 12 study lakes. Due to low oxygen levels during winter months, trout from one of these sites, Birch Lake, appeared to have suffered a winterkill in 2005-2006 (R. Konynenbelt, Alberta Sustainable Resource Development, personal communication), perhaps contributing to high recruitment to metamorphosis for wood frogs.

Various sampling methods (e.g., call surveys, funnel traps, pitfall traps, transect surveys) are better equipped to detect and capture certain amphibian species and life history stages over others (Heyer et al. 1994). I chose to use transects and pitfall traps to survey adult and YOY amphibians after the breeding season and into the emergence period. Still, pros and cons are associated with individual methods.

Transects were chosen because they are cheap and easy to sample, thus, allowing me to carry out multiple surveys in a given summer. Yet, this active method suffers from temporal constraints because transects take place over a short period of time, e.g., 10 min, and are strongly affected by weather conditions and time of day, both of which affect amphibian activity levels and visibility. Because of this, transects can also be classified as a snap-shot method for moving or visible individuals. However, multiple visits to a site over a season, at different times of the day, compensate for these limitations. Additionally, visual detection of frogs is strongly influenced by vegetation height and density, as well as the ability of surveyors to travel through an area, making comparisons between sites or time periods problematic. A good example of limitations associated with transects occurred on Teal Lake. In 2007, I dropped this lake from my study because by July most of the shoreline was covered by dense grasses, over 1 m tall, which made it nearly impossible to detect amphibians at ground level (C. Schank, University of Alberta, unpublished data).

In contrast, pitfall traps are passive gear that intercept moving animals and integrate results over a longer time period. Pitfall traps are at work continuously, and perform well when densities of animals are low or animals move at night. It is well known that larger age classes and certain taxa of amphibians are more likely to escape from traps than others (Parris 1999; Enge 2001). Pitfall traps are labour intensive to construct, but relatively easy to maintain once installed, with the largest effort required to repair fences when damaged by weather or large mammals. The greater the proportion of the perimeter of a water body that is surrounded by traps and fences, the more effective the trapping. Continuous trap-lines become impractical to install and check regularly on larger lakes and wetlands, such as I sampled. My pitfall traps were most effective for sampling YOY, thus were constructed in areas where surveyors heard large choruses of male wood frogs and found egg masses. I assumed that when tadpoles hatched they would stay in the general area and emerge there as metamorphs. This was not the case, apparently, since the majority of pitfall traps captured few to no amphibians. Over the 20 pitfall trap sampling periods, 75 % of YOY amphibians (of all 3 species) were captured

in 8 of 24 traps. I speculate that once eggs hatched, tadpoles migrated to nearby habitats that contained high quality food or shelter. Likewise, metamorphs may have aggregated at other sites that offered easy access to terrestrial habitat or low risk of predation or dehydration.

Since transects and pitfall traps both did not cover the whole shoreline of a lake, there is a chance that surveys were carried out in "cold spots", rather than in areas of naturally high abundances, "hot spots". Patchiness could reflect habitat structure, predator pressures, or food availability. Generally at each lake there was a single transect or pitfall trap array that regularly produced adult and or YOY amphibians during each visit; conversely there were other sites that rarely contained amphibians. For example, in 2006 (to compare with the 20 pitfall trap sampling periods above), over the 11 transect sampling periods, 50 % of amphibians (adult and YOY of all 3 amphibian species) were found in 14 of 45 transects. When looking solely at the YOY age class for all 3 amphibian species, 49 % of YOY were found on 8 of 45 transects. Interestingly, 19 % of adult and YOY, and 30 % of just YOY wood frogs, were found at Yellowhead alone. Because of natural variability along lakes shorelines, the amount of sampling effort invested is an important consideration in designing programs to monitor the effects of management strategies, such as stocking or recreational development, on amphibian populations.

### 5.7 Indirect Effects of Predation: Body Size and Development Patterns

In freshwater systems, growth rates, development patterns, and body sizes of adult and YOY anuran have all been reported to change in response to predation from both invertebrates (Werner and Anholt 1996; Hirai and Hidaka 2002; Relyea 2003; Richter-Boix et al. 2007) and vertebrates (Figiel and Semilitsch 1990; Kiesecker et al. 2001; Van Buskirk and Arioli 2005). Changes in the body size structure of a population can reflect the direct effects of size-selective predation on either small or large individuals (Babbitt and Tanner 1998). Body size can also change if predation risk indirectly affects development and growth of the prey (Nystroem 2001) or predation decreases or increases competition among surviving individuals (Relyea 2004; Relyea and Auld 2005).

Amphibians display a variety of antipredator adaptations (e.g., phenotypic plasticity, life history modifications, altered activity and foraging behaviours, unpalatable toxins) that reduce encounter rates with predators and resulting mortality. Experimental studies have shown antipredator behaviour in larval amphibians can be affected by native invertebrate predators (dragonfly nymphs: Altwegg and Reyer 2003; Kraft et al. 2005), introduced invertebrate predators (crayfish: Cruz et al. 2006) and native fish (Figiel and Semilitsch 1990) or predatory amphibians (Kiesecker et al. 1998). These responses can come at an energetic cost and alter emergence date and/or body size. For example, Kiesecker and Blaustein (1998) exposed Red-legged frog (*Rana aurora*) tadpoles to both adult and larval bullfrogs; time to metamorphosis for *R. aurora* increased in the presence of both bullfrog life history stages. *Rana aurora* has also been documented to emerge at a smaller size from water bodies containing predators (Kiesecker and Blaustein 1998; Kiesecker et al. 2002). In the presence of predatory trout, tadpoles have been observed to be highly vulnerable (Vredenburg 2004), leading to reductions in activity and feeding

(Figiel and Semilitsch 1990; Kiesecker 2002) which can reduce size at emergence (Kiesecker et al. 2002).

Based on findings such as Kiesecker's, I had predicted that YOY wood frogs would metamorphose earlier and at a smaller body size in the lakes stocked with trout versus unstocked lakes. However, I found no evidence that growth and development of wood frogs were affected by trout stocking. Size at metamorphosis was quite stable across the 3 study years; although this measurement did vary among individual lakes, variation was independent of the presence of trout. Other studies have also reported that amphibian body size and emergence patterns (spotted salamander: Figiel and Semilitsch 1990; golden bell frog, *Litoria aurea*: Hamer et al. 2002) did not differ in the presence of introduced fish. The lack of consistent findings is likely linked to the biology of amphibian species, and abiotic and biotic influences (i.e., geographic location, nutrient inputs, and invasive species) of the water body.

I compared the size of YOY wood frogs found at my study lakes to results from experimental study ponds with and without fish at the Meanook Biological Field Station, Alberta and natural ponds without fish in the Beaver Hills, Aspen Parkland of Central Alberta. Young-of-year wood frogs from experimental ponds, with and without small-bodied fish, metamorphosed at a mean SUL of 23.3 mm and 14.8 mm, respectively (Eaton 2004). Mean SUL of YOY wood frogs from natural, fishless ponds in the Beaver Hills ranged from 20 to 22 mm (Eaves 2004). Young-of-year wood frog SUL from Eaton's fish-bearing ponds are comparable to what I found at fish-bearing lakes (mean SUL = 24.2 mm) of my study. However, I found that YOY wood frogs in the boreal foothills were larger in a fishless lake (mean SUL = 25.1 mm), compared to the mean of YOY wood frogs from fishless ponds of Eaton (2004) and Eaves (2004) studies. Since Eaton stocked ponds with high densities of tadpoles, smaller mean wood frog SUL at metamorphosis may be an artifact of over-crowding. Smaller YOY wood frogs seen in Eaves (2004) study may be caused by natural over-crowding due to limited breeding ponds which could increase competition for resources and food, or there could be a greater threat of pond drying, causing tadpoles to potentially transform faster and emerge at smaller sizes in the Beaver Hills compared the Boreal Foothills of Alberta.

Predation has been linked to changes in timing of metamorphosis (Downie et al. 2004), but was not found to affect date at metamorphosis at my study lakes, which was centered at day 209 (July 28$^{th}$). Using 14 species of amphibians (13 from Trinidad and *Xenupus laevis*) in a laboratory experiment, Downie and others (2004) found the larger a tadpole was before metamorphosis, the longer it took to complete its transformation. During this time, amphibians are particularly vulnerable to predation due to reduction in swimming performance. I did not measure tadpole size or growth rate so I can not compare tadpole sizes between treatments prior to metamorphosis and at date of metamophosis. It would be interesting to study trout effects on the tadpole life history stage to determine if stocked trout are affecting tadpole growth and development rates.

The length of the larval period is a trade-off of the relative costs and benefits of remaining in the aquatic environment versus metamorphosing (Figiel and Semlitsch

1990). If the aquatic environment does not pose immediate threats, then metamorphosis could be delayed. This is especially true if the terrestrial environment does not offer safety from predators, abundant food sources or high quality habitats. As well, if tadpoles reach metamorphosis quickly, while compromising size to avoid predation, survival and eventual reproductive success may be reduced as individuals enter the terrestrial environment in poor condition (Berven & Gill 1983; Woodward 1983, 1987; Smith1987; Berven 1990; Scott 1994). The opposite is also true, if metamorphosis is delayed, newly metamorphosed amphibians may not have sufficient time to store fat for winter survival (Berven and Gill 1983); in many temperate ectotherms, small body size of YOY leads to reduced overwinter survival (Danylchuk and Fox 1994; Danylchuk and Tonn 2003).

Resource availability, in addition to predation, can influence amphibian life history traits. Anholt and Werner (1998) showed that wood frog tadpoles will reduce activity levels with both increased predator density and resource availability, affecting growth rates. Eaton et al. (2005) showed that intraspecific competition decreased wood frog size at metamorphosis and may be linked to resource availability and over-crowding. Adult wood frogs co-existing with trout did not appear to experience costs or stresses that reduced body size, with the possible exception of adult wood frogs on Ironside Lake.

Since the quality of the larval environment has the potential to affect life-long traits in anuran amphibians, one might predict that "normal" sized YOY wood frog emerging from stocked lakes would survive to give rise to "normal" sized adults, comparable to adults from unstocked lakes. This was indeed the case when I examined adult size across all lakes and year together, or on a monthly basis for 2006, alone. In the Beaver Hills in the aspen parkland of central Alberta, adult wood frogs (mean SUL range: 34 - 40 mm; Eaves 2004) were found to be smaller than adult wood frogs I found in the boreal foothills (mean SUL range: 37 - 44 mm). These patterns may be shaped by temperature, growth rates, and food availability, at each location.

### 5.8 Does Wood Frog Body Size Affect Predation Risk?

Gape limitation can be applied to any predator-prey relationship but is especially important in predators that engulf their prey whole (Schmitt and Holbrook 1984; Bannon and Ringler 1986). The largest size of prey that a fish can consume is ultimately limited by the vertical and horizontal dimensions of its gape. Because of this physical limitation, trout in my study lakes may be focusing on prey other than amphibians.

I wished to determine if trout in my study lakes are capable of consuming adult and juvenile wood frogs. Using gape regression equations from brown (Bannon and Ringler 1986) and rainbow (Ebner et al. 2007) trout, total lengths of smallest and largest brown trout (203 and 468 mm) and rainbow trout (106 mm and 505 mm) caught from my study lakes (J. Hanisch, University of Alberta, personal communication), and wood frog body width (distance between two shoulder joints) measured on museum specimens, I was able to determine maximum wood frog body width that could be consumed by trout. Body width was chosen over SUL since it is assumed that trout capture the anterior or posterior

end of their prey, so I measured the widest point on a frog's body that would limit handling and swallowing by a fish predator. The smallest and largest brown trout could engulf wood frogs with body width 20 mm and 37 mm, respectively; and the smallest and largest rainbow trout caught could consume wood frogs with body width ca.12 and 66 mm, respectively. Body width and SUL of measured specimens were highly correlated ($R^2 = 0.961$). Therefore, calculated wood frog body widths from the smallest and largest brown trout translate into wood frog SUL of 46 and 82 mm, and from the smallest and largest rainbow trout, wood frog SUL translates into 28 and 145 mm. For the largest stocked fish caught, the maximum sized wood frog (SUL = 145 mm) that could be swallowed is much larger than the largest wood frog (SUL = 57 mm) found in my study area, or ever recorded anywhere. In stocked lakes, if the opportunity arises, trout could consume small to large wood frogs.

As noted, diet analysis provided no evidence that trout ate adult wood frogs. It is quite possible that, even though trout are capable of ingesting wood frogs of a variety of sizes, they seldom encounter them. Adult wood frogs are primarily active in heavily vegetated inshore habitats, too shallow and warm to be attractive to foraging trout. Tadpoles may benefit from similar habitat segregation from trout, but may not be able to avoid contact with small-bodied fishes easily.

### 5.9 Lakes With and Without Fish

In 2006 and 2007, I sampled a fishless lake, Dog Paw, as well as 11 lakes with native small-bodied fishes, of which 5 lakes also contained stocked trout. Since, I found little evidence that trout affected amphibian populations in boreal foothills lakes, I wished to determine if the presence of any species of fish, native or introduced, represented a more fundamental pressure on amphibians. Other studies have reported that even small-bodied fishes can prey upon amphibian eggs and larvae (Laurila et al. 2002; Laurila and Aho 1997). In experimental ponds, Eaton (2004) observed that adult fathead minnows and brook stickleback suppressed activity of wood frog tadpoles and dramatically reduced survival to metamorphosis. Similarly, in natural lakes in the boreal mixed-wood forest of Alberta, Eaton and others (2005) documented increases in the production of wood frog metamorphs in natural lakes in the boreal mixed-wood forest of Alberta after winterkill reduced densities of cyprinids and sticklebacks. In my study lakes, although large trout could be effective predators on eggs or tadpoles, small-bodied fishes and predacious invertebrates are much more numerous and more likely to encounter small, vulnerable amphibian life stages, due to overlapping habitats. Also, if trout prey preferentially on large predatory invertebrates or small-bodied fish, rather that eating tadpoles, they may indirectly increase tadpole survival by altering predacious invertebrates and small-bodied fish populations or behaviour (Hero et al. 1998; Smith et al. 1999; Bryan et al. 2002; Adams et al. 2003).

I found that the presence of fish of any kind was associated with a lower relative abundance of adult wood frogs and smaller adult body size compared to the fishless lake in 2006 and 2007. This higher abundance of larger adult wood frogs suggests that they may be selecting fishless lakes as breeding and foraging sites. Parameters for YOY wood

frogs were more variable between years, but suggested negative effects of fish presence. The relative abundance of YOY wood frog and size at metamorphosis were greater in the fishless lake for 2006 and 2007. As noted for comparisons between stocked and unstocked lakes in 2005-2007, date at metamorphosis was stable and did not differ between lakes with and without fish.

During initial surveys of 10 unstocked lakes to select sites to include in the study, I did not find a single lake (with or without fish) lacking amphibians. These small shallow lakes are dynamic systems, and fish-winterkills, followed by re-colonization or recovery of native fish populations, may mean that amphibian populations are frequently exposed to dramatic fluctuations in population sizes of small-bodied fishes, and may respond accordingly. Similarly, amphibian populations co-existing with fishes may be bolstered by terrestrial immigrants from neighboring wetlands, which may lack fish predators but do not retain water long enough in most years to ensure survival of tadpoles to metamorphosis. My observations suggest that use of shallower wetlands near lakes for breeding may be typical of amphibians, particularly boreal chorus frogs. Artificial aeration of lakes, such as Ironside and Mitchell Lake, to increase overwinter survival of trout, may negatively affect amphibian populations, not by affecting densities of trout, but by enhancing survival of minnows and sticklebacks.

### 5.10 Lake and Year Effects

For all 3 amphibian species, I repeatedly found significant effects of year and lake identity (regardless of stocking treatment) on relative abundance and body size. Annual variability and between site variation in temperature and precipitation make it challenging to assess the effects of trout and other fishes on amphibian populations. Variation in temperature and precipitation can affect amphibians' activities (Sexton et al. 1990; Vasconcelos and Calhoun 2004; Brown and Shine 2007; Koch and Hero 2007). It has been documented that warmer water temperatures will accelerate tadpole growth (Halverson et al. 2003; Schiesari 2006) and since amphibians are prone to desiccation (Feder 1983) increased frequency of rainfall makes it easier for amphibians to avoid dehydration while moving through the terrestrial landscape (Timm et al. 2007). Precipitation in winter or summer also ensures that ponds are larger and longer lived, promoting increased amphibian reproductive success (Paton and Crouch 2002).

In 2005, the area around Sundre, Alberta (20 km south of Caroline, Alberta) received 257.4 (June), 51.4 (July), and 100.7 (August) mm of rain. In 2006, the area received 98.6, 58.0, and 79.9 mm of rain in June, July, and August, respectively, and in 2007 received 124.6, 54.0, and 94.4 mm of rain, respectively (Environment Canada 2007). As a result, 2005 and 2007 were considered wet years, compared to 2006. Due to reduced precipitation in 2006, water levels on Yellowhead and Dog Leg Lakes fell drastically and the width of exposed riparian zones increased by ca.1.5 m. The dry spell and increase in riparian zone did seem to affect relative abundance of YOY wood frogs on these 2 lakes: YOY relative abundances decreased significantly compared to other lakes. In general, relative abundance of adult wood frogs increased from 2005 to 2007. There was no large increase or decrease for adult boreal chorus frogs and western toad relative abundances

from year to year, but because these species were less abundant, fluctuations in numbers may have been more difficult to detect. Increases and decreases in relative abundances of wood frogs among lakes and years showcase the natural variability typical of amphibian populations (Pechmann et al. 1991).

Environmental parameters such as temperature, dissolved oxygen, maximum depth, macrophyte richness, and pond size have been found to affect amphibian species richness (Merilä et al. 2000; Peltzer and Lagmanovich 2004). There is a wide body of literature demonstrating that temperature directly affects species' performances by affecting larval growth and development. In a laboratory experiment, Anderson and others (2001) found that high temperatures (25.7 °C) allowed Pacific tree frog tadpoles to attain larger mass more quickly to avoid predation. Various studies have shown that different tadpole species increase their growth rate and reach metamorphosis faster at temperatures from 17 - 25 °C (Smith-Gill 1979; Anderson et al. 2001; Alvarez and Nicieza 2002; Schiesari 2006). During the 3 years of this study, mean shallow water temperatures of my study lakes varied from 17.5 - 22.1 °C. In a given year, shallow temperature did not fluctuate greatly from lake to lake, however, temperature varied among years. This variation was likely sufficient to contribute to the differences in wood frog body size seen among years, but did not translate into differences in body size among treatments and lakes, or date at metamorphosis.

Significantly larger adult wood frogs were captured in 2005 versus 2006 and 2007 and in 2006 and 2007 there was a lake by treatment interaction. In particular, adult wood frog size greatly differed among lakes in 2007. More adult wood frogs were seen in 2007, compared to 2005 and 2006. Since there was no treatment effect or year by treatment interaction for adult size and relative abundance, I can rule out stocking as the cause of size differences. Therefore, I propose that unmeasured abiotic or biotic parameters caused these year effects. For example, soil moisture may dictate amphibian migration towards and away from lakes. There may have been a natural die-off of larger older individual wood frogs after 2005, ultimately deflating mean size of adult wood frogs in 2006 and 2007. Or large sized wood frogs may be selected by by terrestrial predators (i.e., great blue heron, *Ardea herodias*, Bull and Farrand 1995) in my study area, due to their conspicuous size.

As is typically the case when natural systems are used in field studies, my study lakes were not identical. This was true among the stocked lakes, which were chosen with recreational, not scientific, goals in mind. As documented, the lakes differed in their water chemistry, and also in more complex habitat features such as size, depth, slope, and macrophyte communities. Because of discrepancies in lake characteristics, some study lakes appeared to offer better habitat for tadpoles. For instance, stocked Yellowhead Lake had shallow, muddy shorelines where I often observed high densities of tadpoles and emerging metamorphs. Steep banks and deep littoral zones, as seen in 2 stocked lakes (Strubel and Birch), provide limited areas for amphibian foraging and refuge for eggs and larvae from large-bodied predatory fish (Porej and Hetherngton 2005).

Riparian habitat differences among lakes can contribute to biased estimates of relative abundance and body size of amphibians, particularly smaller individuals that are harder to see. The nature of shoreline vegetation, including height, stem density and the identity of plant species affected my ability to detect amphibians using visual transects (as discussed above). In addition to riparian vegetation features, the width of riparian zone and extent of shoreline could have affected detectability. It can be assumed that adult and YOY amphibians seek shelter in the forest to avoid desiccation and predators, thus limiting their time in open riparian zones where transect surveys and pitfall traps were located. This could reduce our chances of detecting them.

Three-way interactions involving lake, year, and treatment, reflected the large amount of complex variation that exists naturally among lakes and years. Local and regional abiotic and biotic factors can affect these interactions. Amount of shrub and tree cover, nutrient inputs, hydrology, native and introduced species are all factors that potentially could affect the functioning of a lake ecosystem, eventually affecting amphibian responses to stocking. Climatic factors, on top of local habitat factors, can differentially affect lakes within a region, contributing to year to year, as well as site to site variation in amphibian populations.

## 6. Conclusion

To date, there has been limited documentation of the effect of introduced trout on native amphibians in locations other than high elevation, unproductive lakes. My study was the first to assess the effects of trout stocking on native amphibian assemblages in small boreal foothills lakes in Alberta, which naturally have small-bodied fish as an additional trophic level. Three species of amphibians were present in the boreal foothills (wood frog, boreal chorus frog, western toad) and it can be cautiously said that there is no strong evidence that stocked trout negatively impacted wood frog or western toad populations. Boreal chorus frog populations may have been smaller in the presence of trout, but the species was not eliminated. My results provide managers of recreational fisheries with knowledge on effects of introduced trout on amphibian populations in boreal foothill lakes, and perhaps small, productive lakes elsewhere in Alberta, as it appears that current stocking regimes can continue without generating conservation concerns that these activities are contributing to the global phenomenon of amphibian declines.

### 6.1 North American Fisheries

In western North America, in addition to legal stocking by government personnel, intentional stocking by individual private citizens or sportman's clubs began in the late 1800s. Fish introductions by private citizens were carried out by the transport of fish between water bodies, without evaluation of associated consequences. Legal and illegal stocking was poorly planned and regulated. Because stocking was hap-hazard without co-ordinated management objectives, stocking records and monitoring were absent (Pister 2001; Wiley 2003). Through time, North American inland fisheries experienced a gradual shift in their management regimes. From the late 1800s until mid-1970s, fisheries agencies emphasized enhanced fishing through introductions of non-native

game fish to satisfy angler demand and tourism (Wiley 2006). At a symposium on the management of high mountain lakes in California's national parks (1977), Pister alerted scientists and managers that they should study the effects of introductions on native fauna and to promote ecosystem integrity. In the mid-1900s, fisheries managements started addressing both angler satisfaction and the large-scale, long-term environmental consequences of stocking (Alberta Environment 2006).

### 6.2 Alberta's Fishing Policy

In Alberta, the Eastern Slopes division of Alberta Sustainable Resource Development manages and stocks various-sized lakes with sport-fish to enhance and promote recreational fisheries. Alberta's policy follows 5 steps to complete a management cycle: inventory, planning, applying the tools, monitoring, and adapting. This 5-step plan is used to manage provincially important fisheries, and regionally and locally important populations. Managed systems do not always contain adequate nursery environments to allow fish populations to reproduce successfully and sustain themselves. Therefore, maintenance of recreational fisheries is achieved through regular stocking. Research is needed to manage stocked lakes successfully and better understand how introduced fish affect native systems in Alberta. My study on the effects of stocked trout on amphibians is part of a larger project in the boreal foothills that has examined the effects of introduced trout on native forage fish and macroinvertebrates, lake food webs, and trout diet. Information from such multi-faceted studies will allow better management and conservation decisions in connection with future stocking programs.

### 6.3 Stocking as a Tool

Stocking has been said to be an "over used tool" in fisheries management (Cooke and Cowx 1999), but this is only true in systems that are not managed efficiently and reliably. For a tool to work properly, it must be used in the right way and in the right circumstance. If the overall managerial goal is to create, promote or enhance recreational fisheries where wild stocks did not occur naturally, stocking can be an effective tool. Depending on the overall goal of a program, there are 4 strategies that can be deployed: stocking for mitigation, stocking for enhancement, stocking for restoration, and stocking for the creation of new fisheries (Cowx 1999). Management of lakes in my study is an example of the last strategy.

Stocking water bodies to create new fisheries is one of the most controversial stocking procedures, due to the introduction of non-native species in an attempt to improve fish yield and diversity (Cowx 1999). Stocking of non-native fish has been labeled a poor management activity even though introduced species may have the ability to inhabit vacant niches, potentially having no impact on native species (Cowx 1999; Gibson et al. 1999). This is because the formation of new fisheries through stocking can modify ecosystem function and create a large human imprint.

### 6.4 Management Actions

Today fish are not stocked into water bodies without purpose. Stocking designs handle different types of angler demands, and the receiving systems are managed accordingly so that the water body can support the fishery. In areas where anglers want to catch trophy fish, lakes are stocked and managed as catch-and-release fisheries. In these systems, fish are stocked at larger sizes but fewer individuals. These trophy fish provide anglers with satisfying and quality angling opportunities (Askey et al. 2006). In this type of fishery, fish mortality is greatly reduced compared to put-and-take fisheries because harvesting is illegal. However, some mortality results because of physiological stresses related to hooking, removal of fish from the water, handling, illegal harvest, and replacement (J. Hanisch, University of Alberta, personal communication). Anglers also want fisheries where fishing time is low, and harvest is high. Therefore, lakes are stocked and managed as put-and-take, or family fisheries. In family fisheries, the number of fish stocked is greatly increased and size decreased.

In stocked water bodies where fisheries cannot sustain themselves because breeding streams and substrates are unavailable, annual or biennial stocking is needed to maintain the stock and fishery. When estimating the cost of annual stocking, the type of fishery, stocking frequency, and the species used will directly affect costs. In terms of hatchery production costs, a relationship exists between the cost to rear a fish and size at stocking (Cowx 1999). Generally, it costs more to raise large fish. Using rainbow trout as a model, 10 -15 cm trout cost about $0.75 CDN per fish, whereas 15 – 20 cm trout cost around $1.05 per fish (R. Konynenbelt, Alberta Sustainable Resource Development, personal communication). Depending on the type of fishery that is created (i.e., catch-and-release or put-and-take fishery), the number and size of fish drive the overall cost. The cost of rearing and introducing fish is a factor that must be considered during the planning stages for stocking a lake.

Management strategies that promote successful fisheries also incorporate human dimensions such as angling quality and satisfaction. Anglers tend to value one lake over another based on high fish harvest (fishing effort), travel time, and public access. It can be assumed that when catch rate is high and fishing effort is low, anglers will be satisfied. It has been documented that urban fisheries tend to receive more anglers, but if fishing effort increases, anglers may seek new, more distant fisheries (Post et al. 2002). A fishery that receives an increase in total angler effort may see rapid fish removal, leading to a reduction in catch rates (Post et al. 2002; Cooke and Cowx 2004). Therefore, angler satisfaction can dictate if a fishery is successful or not. Success is defined by number of angler visitations; the higher angler use, the more successful the fishery. However, low catch rates can drive anglers away (Cooke and Cowx 2004). Harvest regulations can be set in place to try and reduce over-fishing. If not managed properly, inappropriate harvest can lead to a collapse of the stocked population, or even a collapse of native forage fish through unsustainable predation rates.

### 6.5 Use of Fish Hatcheries

The use of hatcheries to brood fish to promote recreational fisheries through stocking has gained a lot of publicity. However, publicity has generally focused on both the beneficial and damaging contributions of introduced trout to local and regional economies, societal and tourism gains, and not on the ecological costs of stocking. Anglers are demanding short-term instead of long-term fixes when mitigating or creating fisheries (Cowx 2002). People fish for different reasons; some anglers fish for recreational enjoyment, rest-and-relaxation, and others fish for the sport. However, not all anglers are aware of the effects of introducing non-native fish into lakes (C. Schank, University of Alberta, personal observation). Fisheries may be perceived as part of an endless cycle of supply-and-demand and not as what they actually are – limited resources artificially managed as unlimited resources. Hilborn and Eggers (2000) have confronted this issue by declaring that hatchery and government personnel are not initiating scientifically sound experimental studies and programs that look at immediate impacts of introduced species on native species. Instead they use hatcheries as a way to augment total fish production in response to angler demand. For stocking to be recognized as an effective, justifiable management action, fisheries managers need to consider anglers' knowledge, perception, demands, and motivations.

Management of recreational fisheries intended for stocking has been facilitated through the use of hatchery operations. However, hatcheries are known to offer unnatural living conditions because sport-fish are raised in closed, domestic fish pens and fed by hand. Fish do not experience natural predation, or inter- and intraspecific competition (White et al. 1995). Care must be taken to manage hatchery fish so that no outside pathogens invade and decimate populations before fish can be stocked. Similarly, housing conditions have been found to increase fish's susceptibility to various hatchery-based pathogenic molds (Kiesecker et al. 2001) and induce pre-mature mortality and fitness loss once sport-fish are placed into a lake or stream (White et al. 1995).

In the last 15 years, malachite green, which controlled pathogenic water molds (*Saprolegnia ferax*) in hatchery rainbow trout, was banned because it linked to teratogenicity (i.e., embryonic malformations). With the ban of malachite green, *S. ferax* persisted and found its way into natural water bodies via hatchery-reared trout (Kiesecker et al 2001). *Saprolegnia ferax* infects and kills native aquatic biota, particularly amphibians, and drastically reduces their numbers (Kiesecker et al. 2001). This water mold should be monitored to reduce its spread in natural systems.

Because hatchery-reared sport-fish spend most of their lives in predator-free environments, fish do not develop antipredator behaviours and lose their pre-disposition toward adaptive behaviour the longer they live under hatchery conditions (White et al. 1995). Poor post-stocking survival can result due to high vulnerability to natural predators (Bachman 1984), and loss of behaviours that would lead to concealment in refuges and predator avoidance (Ritter and MacCrimmon 1973; Roadhouse et al. 1986). Pre- and post-stocking conditions and behaviours of hatchery-reared fish should be

studied so that sport-fish do not experience high mortality once stocked into a natural water body.

### 6.6 Stocking Decisions

One objective of many lake stocking programs is to assure that introduced fish do not disperse into other water bodies and prey on or compete with native fauna. Dispersal of non-native fish is serious because invasive species may out-compete native fauna, altering food webs and ecosystem function. Non-native fish may hybridize with native fish, eventually altering the native gene pool. In Alberta, Fish and Wildlife personnel deal with this issue by establishing lake and fish criteria for stocking. First, lakes with closed basins or outlets are chosen as potential stocking lakes so that dispersal is strictly limited. Secondly, in case stocked fish do disperse themselves or through human transport, hatcheries produce sterile, triploid rainbow trout. Consequently, if stocked fish disperse they cannot establish breeding populations. The cost of using triploid fish is 5 % more than using diploid fish (R. Konynenbelt, Alberta Sustainable Resource Development, personal communication). However, this cost is justified in the long run, as it reduces the chance of dispersal-establishment-reproduction events, which could be very expensive to reverse.

Another important stocking decision is choosing the fish species to stock. Management needs to know the diet, life history, and catchability of candidate species to determine how fish will interact with the receiving systems and anglers. Trout species display different levels of aggressiveness towards prey and different feeding behaviours although they are commonly dietary generalists (Behnke 1992; Nelson and Paetz 1992; Hubert and Gipson 1994; Haddix and Budy 2005). Brook trout, compared to rainbow trout, feed more opportunistically on multiple prey species (Dawidowicz and Giliwicz 1983) and prefer large, conspicuous prey (Allan 1978). Potential prey species should be assessed to verify that a sustainable supply of trout food exists within a lake being considered for stocking.

In terms of catchability, the brook trout is a "fighter" when hooked by an angler, displaying considerable resistance to being landed (Nelson and Paetz 1992). Rainbow trout are thought to be easier to catch than brook trout, making them more appropriate for family fisheries. Recently, Askey and others (2006) found that rainbow trout exhibit learned behaviours with increased angling pressure. In catch-and-release lakes, a rainbow trout learns, with each landing, to avoid hooks, making it harder to catch. When fisheries managers evaluate which trout species to stock in a lake, they must weigh a variety of factors, and choose the species that will have minimal negative effects of native biota, yet create an attractive fishery.

### 6.7 Recommendations

My study examined trout-amphibian interactions under novel environmental conditions in small boreal foothills lakes, improving and augmenting our understanding of the consequences of stocking trout. I documented amphibian relative abundances, body

sizes, and patterns of metamorphosis in the presence and absence of stocked trout, within systems that supported native forage fish. Information gained from my study will assist Alberta Conservation Association and Alberta Sustainable Resource Development in evaluating the consequences of trout stocking on the biota of the boreal foothills and help shape future management strategies.

Stocking sport-fish from hatcheries into water bodies is an important tool in the management of recreational fisheries. This style of creating and maintaining fisheries converges on fish farming as populations are established; fish are grown to adequate sizes then are harvested by the general public. I am offering the following recommendations for trout stocking in the Alberta Eastern Slopes Region in order to move from traditional management of fisheries resources towards integrated management of water bodies and native amphibian populations. I am aware that the majority of these recommendations are already practiced or under consideration. My main purpose is to express those recommendations in the context of my research results and experience.

*General recommendations*

1. Through my visits to each lake and my conversations with local anglers, it became evident that the public was interested in the research that I was conducting on the larger scale effects of trout stocking. I recommend that improved communication and education programs addressing the consequences of species introductions and stocking, protection of aquatic systems, and conservation of native aquatic biota be developed around recreational fisheries.
2. Objectives and goals of a stocking program should be clearly defined before implementation. Alternate approaches should be explored, and costs and benefits evaluated. Also, long-term effects of stocking and possible indirect consequences should be recognized and influence decisions.
3. Fisheries managers need to address 3 concerns. (1) Ethical concerns – the use of hatcheries to brood fish for stocking can cause some ethical issues regarding fish rearing, handling, and stocking into water bodies with native fish or with no large predators. Furthermore, the quality of life of hatchery fish when stocked into receiving water bodies should be of concern, since we are introducing hatchery reared fish into systems with which they are not familiar and adapted. (2) Conservation concerns – conservation issues needs to address the effects of introduced species on native flora, fauna, and abiotic factors. (3) Economic concerns – issues relating to the cost of operating hatcheries, rearing fish, stocking fish, and managing recreational fisheries.
4. When stocking is being proposed as a method to create a new or enhance an existing fishery, both abiotic and biotic environments and genetic factors must be assessed to understand the full suite of consequences. In systems with native trout, introduced and wild stocks may hybridize, or introduced trout may out compete wild trout, altering gene pools
5. The species of fish, size of fish, and timing of stocking should be examined at the planning stage. These effects can make or break a fishery. Data collection before, during, and after stocking is needed to document the effects of the trout on the lake environment and aquatic biota. A fishery can be deemed successful only

if stable populations of native organisms coexist with stocked fish and the physical environment is not altered and provides refuge for native organisms, allowing potential prey species to persist with stocked trout.

6. Sport-fish that are stocked into receiving water bodies are not accustomed to natural environments and may experience increased mortality over and above mortality rates of wild fish. They are also susceptible to weight loss. Mortality and weight loss can be caused by competition and stress (Vøllestad & Hesthagen 2001). If stocked fish fail to survive in their new environment, and angling efforts lessen in response to declines in catchable fish, fisheries will generate monetary losses. To ensure a positive balance between the costs of stocking lakes and economic gains, and to prolong the life of fisheries, I recommend that managers involved with hatcheries and stocking programs monitor hatchery-reared fish weight loss and factors such as disease that may reduce post-stocking survival. This can be done through regular sub-sampling of stocked populations and the measurement of growth rates and condition.

*Specific recommendations based on trout-amphibian relations*

1. I propose that one strategy to reduce the likelihood of negative trout-amphibian interactions is to make the date of stocking flexible. Even though trout in my study lakes have not been observed to prey on any life-stage of native amphibians (J. Hanisch, University of Alberta, personal communication), other studies have shown that trout do consume amphibians. If stocking occurred after the wood frog breeding season, when eggs have hatched and tadpoles dispersed, then the risk of trout predation would be reduced.
2. Piscivorous fish have been documented to capture successfully and ingest larvae, metamorphs, and adult amphibians, as well as invertebrates and forage fish (Bradford et al. 1983; Laurila and Aho 1997; Gillespie 2001; Laurila et al. 2002; Baber and Babbitt 2003; Murray and Wirsing 2004; Mirza et al. 2006; Saglio and Mandrillon 2006; Touchon et al. 2006; Gomez-Mestre and Warkentin 2007). Wood frogs are explosive breeders, thus their peak breeding season lasts for approximately 1 week (shortly after ice-off: mid to late April), and based on temperature, eggs hatch within 1 - 2 weeks of being laid (Waldman 1982). I would recommend that stocking take place no earlier than late May to give amphibian larvae time to hatch, grow and seek refuge.
3. In Alberta, some lakes prone to winterkill events are artificially aerated to promote fish survival. For aerated lakes an alternative to recommendation 1 is to reduce the risk of trout preying on amphibians by delaying stocking until late August, after metamorphosis has occurred.
4. When my study began there were no data on how amphibians responded to stocked trout in the boreal foothills. I and my collaborators in the FIESTA Project performed a "control-impact" study on our 12 study lakes from 2005 through 2007. However, to fully understand what is happening in these systems and to verify results to date, I propose that a Before-After-Control-Impact (BACI) design would document the effects of trout more clearly by examining lakes before and after stocking is first initiated. This approach is now viable because we have accumulated 3 years of baseline data on stocked and unstocked lakes.

Fortunately, in fall 2007, after my field work ended, one of the unstocked study lakes, Fiesta Lake, was stocked with triploid rainbow trout. This management action will allow a test of the robustness of my results and conclusions and document response of amphibian populations immediately after stocking.

To conserve time and money, I would recommend carrying out a shorter amphibian survey than conducted in 2006. I performed call surveys over the entire wood frog breeding season and determined that this survey technique was not an effective way of assessing breeding activity quantitatively and only worked to document presence/absence. Lakes only need to be visited enough times to detect presence/absence of calling males and to verify if breeding was successful through egg mass counts. To sample amphibians during the rest of their active seaon on boreal foothills lakes, transect surveys would be the best method to utilize because they are cheap, quick, and easy to set up and conduct. They allow surveyors to detect both adult and young-of-year amphibians and thus assess reproductive success. Even though trout do not seem to be negatively affecting amphibian populations (except adult boreal chorus frogs), fisheries managers should continue to conduct amphibian surveys to gather long-term data, that will assess trends and patterns of trout-amphibian interactions.

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Table 1. Physical characteristics of all 12 study lakes in the boreal foothills, Alberta.

| Lakes | UTM | Area (ha) | Maximum Depth (m) | Elevation (Feet) |
|---|---|---|---|---|
| Ironside | 0636765<br>5790376 | 3.3 | 12.5 | 3415 |
| Mitchell | 0633970<br>5786934 | 15.0 | 6 | 3426 |
| Yellowhead | 0650649<br>5758595 | 24.5 | 12.2 | 3869 |
| Strubel | 0636606<br>5785307 | 25.9 | 12.5 | 3484 |
| Birch | 0647365<br>5764866 | 28.8 | 8.5 | 3914 |
| Gun Range | 0656986<br>5764866 | 5.9 | 13.4 | 3747 |
| Dog Leg | 0655805<br>5762187 | 6.7 | 5.05 | 3791 |
| Fiesta | 0656200<br>5762760 | 7.1 | 6.6 | 3730 |
| Picard | 0657555<br>5760154 | 8.7 | 5.4 | 3768 |
| Teal | 0658966<br>5761776 | 16.5 | 9.0 | 3735 |
| Gas Plant | 0653906<br>5762292 | 17.5 | 3.25 | 3849 |
| Dog Paw | 0656068<br>5760720 | 1.8 | 4.0 | 3732 |

Table 2. Information for 12 study lakes in the boreal foothills, Alberta on stocking status, native and non-native species presence.

| Lakes | Type of Stocking | *Native Amphibians | **Stocked Nonnative Fish | ***Native Fish |
|---|---|---|---|---|
| Ironside | Stocked | Wood frog<br>Boreal chorus frog<br>Western toad | Rainbow trout | Dace **** |
| Mitchell | Stocked | Wood frog<br>Boreal chorus frog<br>Western toad | Rainbow trout<br>&<br>Brown trout | Dace **** |
| Yellowhead | Stocked | Wood frog<br>Boreal chorus frog<br>Western toad | Brook trout | Dace ****<br>Fathead minnow,<br>Brook stickleback,<br>Iowa darter |
| Strubel | Stocked | Wood frog<br>Boreal chorus frog<br>Western toad | Rainbow trout | Dace ****<br>Brook stickleback |
| Birch | Stocked | Wood frog<br>Boreal chorus frog<br>Western toad | Brook trout | Dace ****<br>Fathead minnow Brook stickleback |
| Dog Leg | Unstocked | Wood frog<br>Boreal chorus frog<br>Western toad | Absent | Dace ****<br>Fathead minnow,<br>Brook stickleback |
| Fiesta | Unstocked | Wood frog<br>Boreal chorus frog<br>Western toad | Absent | Dace ****<br>Fathead minnow,<br>Brook stickleback |

Table 2 continued.

| Lakes | Type of Stocking | *Native Amphibians | **Stocked Nonnative Fish | ***Native Fish |
|---|---|---|---|---|
| Gun Range | Unstocked | Wood frog<br>Boreal chorus frog<br>Western toad | Absent | Dace ****<br>Fathead minnow,<br>Brook stickleback |
| Picard | Unstocked | Wood frog<br>Boreal chorus frog<br>Western toad | Absent | Fathead minnow,<br>Brook Stickleback |
| Teal | Unstocked | Wood frog<br>Boreal chorus frog<br>Western toad | Absent | Dace ****<br>Fathead minnow,<br>Brook stickleback |
| Dog Paw | Fishless | Wood frog<br>Boreal chorus frog | Absent | Absent |

* Presence/absence of amphibians was determined by call surveys and/or visual surveys

** Introduced fish species were stocked by Alberta Sustainable Resource Development

*** Native fish species that inhabit study lakes were identified by L. Nasmith

**** Dace include finescale dace (*Phoxinus neogaeus*), northern redbelly dace (*Phoxinus eos*), pearl dace (*Margariscus margarita*), hybrids (finescale crossed with northern redbelly dace) (L. Nasmith, University of Alberta, personal communication).

Table 3. Stocking information for the 5 stocked study lakes. TL = total length

| Lakes | Stocking Dates | Rate of Stocking | Month Stocked | No. stocked trout | Mean size when stocked (TL: cm) |
|---|---|---|---|---|---|
| Ironside | Since 2005 | Annual | June | 250 - 500 | Rainbow trout 25-29 |
| Mitchell | Since 1950 | Annual | May/June | 5000 - 10,000 | Rainbow trout 17-21 Brown trout 6-26 |
| Yellowhead | Since 1983 | Biennial | June | 18,000 | Brook trout 7-10 |
| Strubel | Since 1950 | Annual | May | 18,000 | Rainbow trout 11-15 |
| Birch | Since 1983 | Biennial | June | 16,000 | Brook trout 8 - 10 |

Table 4. Temperature and water chemistry of 12 small boreal foothills study lakes. For each lake the first row is 2005, second row is 2006, and third row is 2007 data. Deep temperature loggers were set below the thermoclime and shallow temperature loggers were set above the thermoclime. Water chemistry included total nitrogen (TN), total phosphorus (TP), dissolved oxygen (DO), chlorophyll-a (Chl-a), and pH. The 2006 pH value for Dog Paw is not the mean of June and July readings: The June value was discarded since the pH was not working properly.

| Lakes | Year | Deep Temperature Logger | Shallow Temperature Logger | TN (µg/L) | TP (µg/L) | DO (µg/L) | Chl-a (µg/L) | pH |
|---|---|---|---|---|---|---|---|---|
| Ironside | 2005 | NA | 19.9 | 812 | 18 | 3.7 | 0.23 | 8.0 |
| | 2006 | NA | 21.9 | 635 | 16 | 5.6 | 2.90 | 7.8 |
| | 2007 | 12.3 | 19.1 | 659 | 13 | 5.7 | 2.00 | 7.9 |
| Mitchell | 2005 | NA | 19.6 | 1071 | 13 | 6.9 | 0.53 | 8.3 |
| | 2006 | 12.1 | 20.1 | 1072 | 16 | 7.8 | 3.20 | 7.9 |
| | 2007 | 16.2 | 19.8 | 930 | 15 | 8.1 | 3.00 | 7.0 |
| Yellowhead | 2005 | NA | 19.0 | 785 | 19 | 5.1 | 0.53 | 8.1 |
| | 2006 | 14.0 | 20.8 | 741 | 16 | 5.9 | 4.94 | 8.2 |
| | 2007 | NA | 18.6 | 754 | 16 | 5.8 | 3.00 | 7.8 |
| Strubel | 2005 | NA | 19.1 | 567 | 8 | 7.1 | 0.24 | 8.4 |
| | 2006 | 20.8 | 22.1 | 480 | 8 | 9.0 | 1.67 | 8.3 |
| | 2007 | 16.6 | 19.0 | 523 | 8 | 9.4 | 1.00 | 8.3 |
| Birch | 2005 | 14.5 | 18.3 | 1092 | 35 | 9.4 | 1.90 | 8.6 |
| | 2006 | 14.7 | NA | 99.8 | 19 | 7.6 | 4.57 | 8.1 |
| | 2007 | 10.2 | 20.0 | 796 | 19 | 7.6 | 5.00 | 8.1 |
| Gun Range | 2005 | 15.5 | 18.8 | 1075 | 30 | 4.0 | 0.29 | 8.1 |
| | 2006 | NA | 20.7 | 1005 | 23 | 5.8 | 7.09 | 7.7 |
| | 2007 | 5.64 | NA | 881 | 22 | 5.5 | 6.00 | 7.9 |
| Dog Leg | 2005 | 13.3 | 19.0 | 1008 | 41 | 4.1 | 1.38 | 7.2 |
| | 2006 | 14.3 | 20.9 | 1006 | 35 | 4.8 | 12.08 | 6.7 |
| | 2007 | 9.4 | 19.3 | 929 | 31 | 4.4 | 7.00 | 7.1 |
| Fiesta | 2005 | 16.1 | 17.5 | 1051 | 48 | 2.8 | 0.59 | 7.4 |
| | 2006 | 7.7 | 21 | 929 | 37 | 4.1 | 12.54 | 7.5 |
| | 2007 | 4.9 | 18.3 | 803 | 25 | 4.3 | 3.00 | 7.7 |
| Picard | 2005 | NA | NA | NA | NA | 10.3 | NA | 8.6 |
| | 2006 | 14.4 | 20.5 | 1022 | 42 | 9.5 | 6.55 | 7.7 |
| | 2007 | NA | NA | 1040 | 25 | 9.1 | 2.00 | 7.9 |

Table 4. continued.

| Lakes | Year | Deep Temperature Logger | Shallow Temperature Logger | TN (µg/L) | TP (µg/L) | DO (µg/L) | Chl-a (µg/L) | pH |
|---|---|---|---|---|---|---|---|---|
| Teal | 2005 | 13.9 | 18.0 | 1099 | 53 | 4.4 | 0.78 | 7.6 |
| | 2006 | 11.2 | 19.2 | 889 | 32 | 4.6 | 8.02 | 7.2 |
| | 2007 | NA | NA | 828 | 26 | 4.4 | 4.00 | NA |
| Gas Plant | 2005 | 15.8 | 18.3 | 909 | 53 | 5.3 | 1.73 | 7.3 |
| | 2006 | 13.6 | 20.7 | 1096 | 51 | 6.2 | 11.29 | 7.0 |
| | 2007 | 10.3 | 19.4 | 957 | 46 | 6.4 | 8.00 | 7.4 |
| Dog Paw | 2005 | NA | NA | NA | NA | NA | NA | NA |
| | 2006 | NA | 20.9 | 967 | 36 | 3.9 | 6.29 | 6.72 |
| | 2007 | 6.1 | NA | 1056 | 47 | 3.4 | 6.00 | 6.8 |

Table 5. Summary of the wood frog call surveys and visual transect survey from 2006, indicating the number of transects, point counts, and number of call codes observed of each Rank over the entire survey period. Number of point counts represent the total number of point counts taken throughout the entire sampling period. Multiple call Ranks could be assigned for a single point count because surveyors were able to distinguish multiple groups of calling males at a single site.

| Treatment | Lake | No. of Transects | No. of Point Counts | No. of observations of call Ranks(0-3) 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|
| Stocked | Ironside | 2 | 6 | 2 | 3 | 0 | 0 |
| | Mitchell | 4 | 9 | 6 | 2 | 1 | 0 |
| | Yellowhead | 5 | 12 | 4 | 8 | 0 | 7 |
| | Strubel | 4 | 9 | 6 | 3 | 0 | 0 |
| | Birch | 6 | 15 | 8 | 5 | 3 | 1 |
| Unstocked | Gun Range | 3 | 6 | 3 | 4 | 0 | 0 |
| | Dog Leg | 3 | 9 | 4 | 1 | 1 | 3 |
| | Fiesta | 3 | 12 | 10 | 2 | 0 | 0 |
| | Picard | 4 | 12 | 7 | 5 | 1 | 0 |
| | Teal | 5 | 15 | 8 | 6 | 1 | 1 |
| | Gas Plant | 5 | 15 | 4 | 7 | 4 | 3 |

Table 6. Environmental parameters [Surface Temperature (Surf. Temp: °C), total nitrogen (TN: (µg/L), total phosphorous (TP: (µg/L), Dissolved Oxygen (DO: µg/L), Chlorophyll-a (Chl-a: µg/L), and pH] table showing Mean ± SE of 3 years and statistical test outputs for stocked (2005, 2006, 2007: 5 lakes ), unstocked (2005: 5 lakes. 2006: 6 lakes, 2007: 5 lakes), and 1 fishless lake (2006 and 2007). SE cannot be calculated for the fishless treatment due to the lack of lake replications. Environmental parameters were compared using a 2-way ANOVA [treatment (stocked and unstocked) and year fixed factors] and a one-sample t-test [11 Fish-bearing (stocked and unstocked combined) lakes versus the 1 fishless lake]. Lake water samples were taken once in 2005 (July), 4 times in 2006 (once in May, June, July, August), and 2 times 2007 (once in June and August).

| | Shallow Temp | TN | TP | DO | Chl-a | pH |
|---|---|---|---|---|---|---|
| Means ± SE | | | | | | |
| Stocked | 19.8 (0.21) | 734.5 (82.30) | 15.9 (2.61) | 7.0 (0.71) | 3.13 (0.43) | 8.1 (0.11) |
| Unstocked | 19.5 (0.27) | 975.4 (15.31) | 36.3 (3.29) | 5.6 (0.87) | 7.30 (0.98) | 7.5 (0.16) |
| Fishless | 20.9 | 1011.50 | 41.5 | 3.7 | 6.2 | 6.8 |
| Stocked versus Unstocked | | | | | | |
| *Test Statistic ($F_{1,9}$)* | | | | | | |
| Treatment | 2.229 | 8.206 | 33.466 | 4.619 | 21.297 | 9.348 |
| Year | 24.883 | 0.409 | 0.113 | 0.114 | 3.633 | 0.115 |
| *P-value* | | | | | | |
| Treatment | 0.158 | 0.012 | 0.001 | 0.050 | 0.001 | 0.009 |
| Year | 0.001 | 0.533 | 0.742 | 0.740 | 0.077 | 0.739 |
| Fish-bearing versus Fishless | | | | | | |
| *2006* | | | | | | |
| Test Statistic ($T_9$) | -0.422 | -1.634 | -2.274 | 5.265 | 0.447 | 6.189 |
| P-value | 0.683 | 0.133 | 0.046 | 0.001 | 0.664 | 0.001 |
| 2007 | | | | | | |
| Test Statistic ($T_{10}$) | NA | -5.189 | -7.934 | 5.391 | -2.966 | 5.343 |
| P-value | NA | 0.001 | 0.001 | 0.001 | 0.014 | 0.001 |

Table 7. Occurrence on transects of adult and young-of-year wood frog, boreal chorus frog, and western toad at 5 stocked lakes, and 5 (2007) or 6 (2007) unstocked lakes, and 1 fishless lake. Presence/absence is presented for species, treatment, total % (all treatments together as a percentage), across years. Wood frog presence/absence is not separated into treatments because adult and young-of-year were found at every lake, in all years.

| Species | Treatment | Adult | | | Young-of-year | | |
|---|---|---|---|---|---|---|---|
| | | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 |
| Wood frog | | | | | | | |
| | Total % Occurence | 100 | 100 | 100 | 100 | 100 | 100 |
| Boreal Chorus Frog | | | | | | | |
| | Stocked | 1/5 | 0/5 | 4/5 | 1/5 | 0/5 | 2/5 |
| | Unstocked | 4/6 | 6/6 | 5/5 | 4/6 | 0/6 | 1/5 |
| | Fishless | NA | 0/1 | 1/1 | NA | 0/1 | 1/1 |
| | % occurence | 45 | 50 | 90 | 45 | 0 | 36 |
| Western Toad | | | | | | | |
| | Stocked | 5/5 | 2/5 | 3/5 | 2/5 | 2/5 | 4/5 |
| | Unstocked | 4/6 | 3/6 | 3/5 | 1/6 | 3/6 | 2/5 |
| | Fishless | NA | 0/1 | 0/1 | NA | 0/1 | 0/1 |
| | % occurence | 91 | 42 | 55 | 18 | 42 | 54 |

Table 8. Summary of the number of wood frog egg masses encountered on 3 locations per lake in 2006. Egg masses counts occurred across 3 survey periods. 1 = April 24th to April 27th; 2 = May 2nd to May 5th; 3 = May 6th to May 13th. Locations searched were sites of Rank 3 chorus during call surveys. If a Rank 3 was not heard at a lake, the next highest Rank identified was searched.

| Treatment locations | Lake | No. Egg Mass Counts at each of 3 survey Sampling Periods | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Stocked | Ironside | 0 | 0 | 1 |
| | Mitchell | 0 | 1 | 0 |
| | Yellowhead | 26 | 107 | 0 |
| | Strubel | 0 | 0 | 0 |
| | Birch | 13 | 0 | 5 |
| Unstocked | Gun Range | 0 | 0 | 0 |
| | Dog Leg | 212 | 152 | 0 |
| | Fiesta | 0 | 0 | 4 |
| | Picard | 0 | 0 | 0 |
| | Teal | 0 | 3 | 0 |
| | Gas Plant | 116 | 0 | 0 |

Table 9. Summary of relative abundance Split-plot and Nested Anova outputs for 3 amphibian species and 2 age classes. Numbers in brackets represent power to detect a difference between stocked and unstocked lakes at 95 % confidence interval (significance level = 0.05).

| AGE | ANALYSIS | SPECIES<br>WOOD FROG | BOREAL CHORUS FROG | WESTERN TOAD |
|---|---|---|---|---|
| **ADULT** | Split-plot | | | |
| | Treatment effects | $F_{1,9}$=4.440; P=.522 (0.092) | $F_{1,10}$=6.038; P=0.021 (0.658) | $F_{1,1}$=0.133;P=0.723 (0.063) |
| | Year X Treatment | $F_{2,18}$=1.536; P=.486 (0.157) | $F_{1,2}$ =0.979; P=0.396 (0.192) | $F_{1,2}$=0.673;P=0.342 (0.215) |
| | Year effect | $F_{2,9}$ =6.716; P=.007 (0.859) | $F_{1,2}$ =2.456; P=0.116 (0.426) | $F_{1,2}$=1.155;P=0.525 (0.142) |
| | YearX Treatment X Lake | $F_{2,18}$=2.226; P=.004 (0.986) | $F_{1,17}$=1.664; P=0.051 (0.926) | $F_{1,15}$=1.680;P=0.056(0.904) |
| | Nested Anova | | | |
| 2005 | Lake X Treatment | $F_{1,9}$=3.745; P=0.001 (0.983) | $F_{1,9}$=4.132; P=0.0001 (0.994) | $F_{1,9}$=2.481;P=0.019 (0.889) |
| 2006 | Lake X Treatment | $F_{1,9}$=4.712; P=0.001 (0.998) | $F_{1,9}$=2.618; P=0.009 (0.928) | $F_{1,9}$=2.337;P=0.020 (0.890) |
| 2007 | Lake X Treatment | $F_{1,8}$=2.841; P=0.008 (0.924) | $F_{1,8}$=1.750; P=0.098 (0.722) | $F_{1,8}$=3.503;P=0.001 (0.973) |
| **YOY** | Split-plot | | | |
| | Treatment effects | $F_{1,9}$=0.458; P=.516 (0.093) | $F_{1,1}$=0.360; P=0.563 (0.084) | $F_{1,1}$=1.107;P=0.320 (0.156) |
| | Year X Treatmen | $F_{2,18}$=1.511; P=.686 (0.102) | $F_{1,1}$=0.199; P=0.667 (0.068) | $F_{1,2}$=0.706;P=0.508 (0.149) |
| | Year effect | $F_{1,2}$ =1.043; P=.374 (0.202) | $F_{1,8}$=1.255; P=0.295 (0.168) | $F_{1,2}$=1.805;P=0.195 (0.324) |
| | YearX Treatment X Lake | $F_{2,18}$=2.558; P=.001 (0.994) | $F_{1,8}$=2.652; P=0.010 (0.916) | $F_{2,17}$=2.517;P=0.001(0.993) |
| | Nested Anova | | | |
| 2005 | Lake X Treatment | $F_{1,9}$=5.838; P=0.000 (1.000) | | |
| 2006 | Lake X Treatment | $F_{1,8}$=3.778; P=0.071 (0.772) | | |
| 2007 | Lake X Treatment | $F_{1,9}$=1.903; P=0.001 (0.981) | | |

Table 10. Summary of wood frog snout-urostyle length split-plot and nested ANOVA output for 2 age classes. Numbers in brackets represent power to detect a difference between stocked and unstocked lakes at 95 % confidence interval (significance level = 0.05).

| AGE | ANALYSIS | OUTPUT | |
|---|---|---|---|
| ADULT | Split-plot ANOVA | | |
| | Treatment effects | $F_{1,10} = 2.890$; P = 0.996 | (0.050) |
| | Year X Treatment | $F_{1,2} = 2.727$; P = 0.084 | (0.492) |
| | Year effect | $F_{2,15} = 5.592$; P = 0.009 | (0.814) |
| | YearX Treatment X Lake | $F_{1,15} = 1.522$; P = 0.090 | (0.880) |
| | Nested ANOVA | | |
| | 2005 Lake X Treatment | $F_{1,8} = 1.401$; P = 0.206 | (0.606) |
| | 2006 Lake X Treatment | $F_{1,9} = 2.589$; P = 0.006 | (0.942) |
| | 2007 Lake X Treatment | $F_{1,8} = 2.229$; P = 0.031 | (0.844) |
| YOY | Split-plot ANOVA | | |
| | Treatment effects | $F_{1,9} = 0.001$; P = .971 | (0.050) |
| | Year X Treatment | $F_{2,17} = 1.570$; P = .227 | (0.303) |
| | Year effect | $F_{2,17} = 1.505$; P = .240 | (0.292) |
| | YearX Treatment X Lake | $F_{2,17} = 3.101$; P = 0.0001 | (0.999) |
| | Nested ANOVA | | |
| | 2005 Lake X Treatment | $F_{1,9} = 8.419$; P = 0.0001 | (1.000) |
| | 2006 Lake X Treatment | $F_{1,9} = 13.552$; P = 0.0001 | (1.000) |
| | 2007 Lake X Treatment | $F_{1,8} = 12.074$; P = 0.0001 | (1.000) |

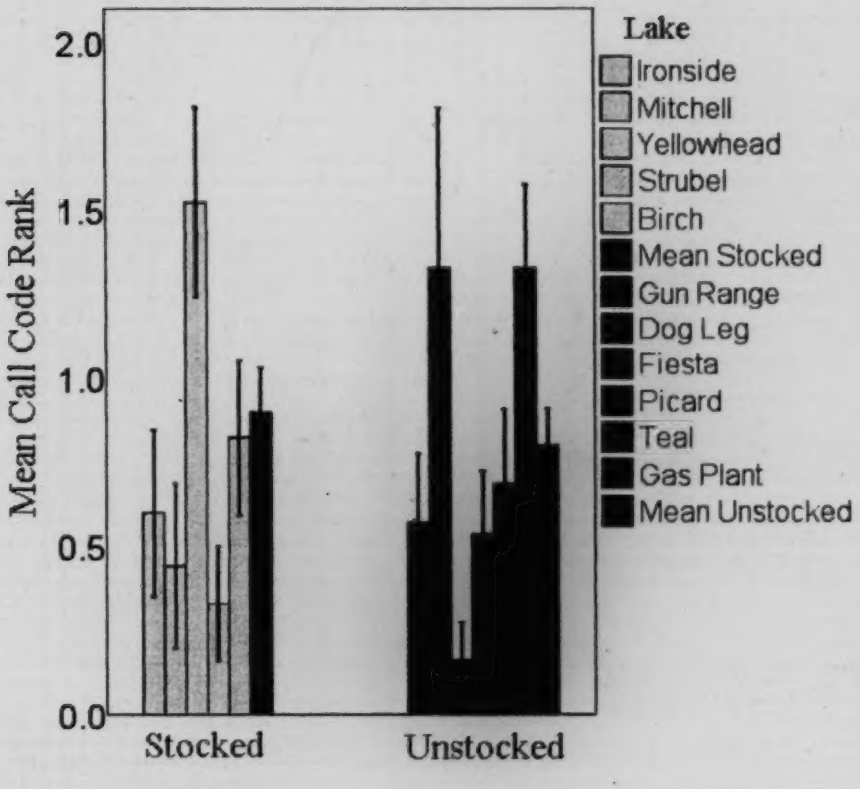



Figure 1. Mean call Rank for adult male wood frogs in 2006 during call surveys at 11 lakes within stocked and unstocked treatments in the boreal foothills of Alberta. Mean calling code is calculated from number of times Rank 0, 1, 2, and 3 choruses were heard on each lake. Bars represent the standard error of the mean. A t-test was done to compare stocked and unstocked treatments. Reading the x-axis left to right matches the legend from top to bottom.

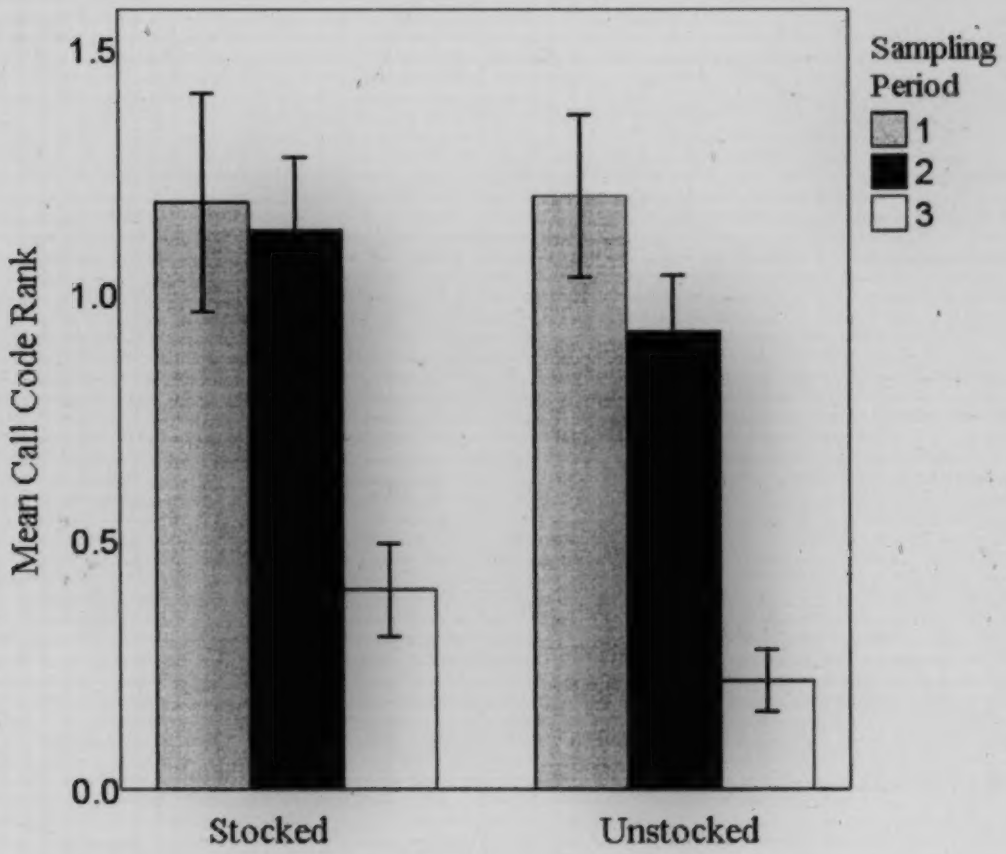



Figure 2. Mean call Rank for adult male wood frogs in 2006 during 3 survey periods at 11 lakes within stocked and unstocked treatments in the boreal foothills of Alberta. Mean call Rank is calculated from number of times Rank 0, 1, 2, and 3 choruses were heard on each lakes. Bars represent the standard error of the mean. 2-way ANOVA compared survey periods among stocked and unstocked treatments. Survey period 1 occurred from April 24 -27, period 2 from May 2-5, and period 3 from May 6-13. Reading the x-axis left to right matches the legend from top to bottom.

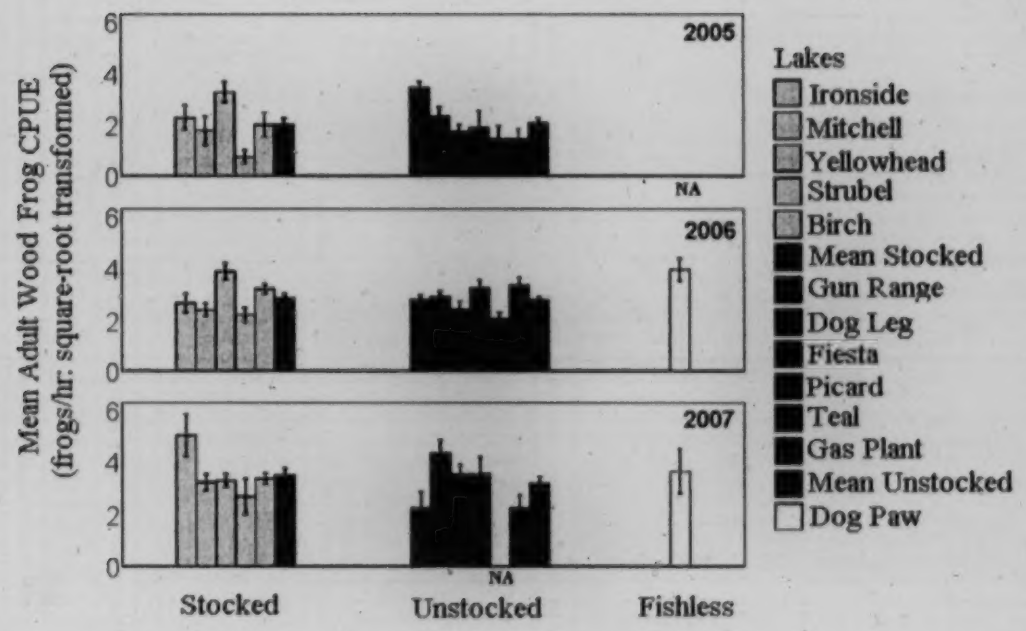



Figure 3. Mean catch-per-unit-effort (CPUE) of adult wood frogs caught along transects at 11 lakes (2005 and 2007) and 12 lakes (2006) within stocked, unstocked, and fishless treatments in the boreal foothills of Alberta. Lake means are calculated using sampling date as unit of replication. Bars represent the standard error of the mean. Split-plot ANOVA carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed with fish-bearing and fishless treatments. Reading lakes on x-axis left to right matches the legend from top to bottom. NA = lake not sampled that year.

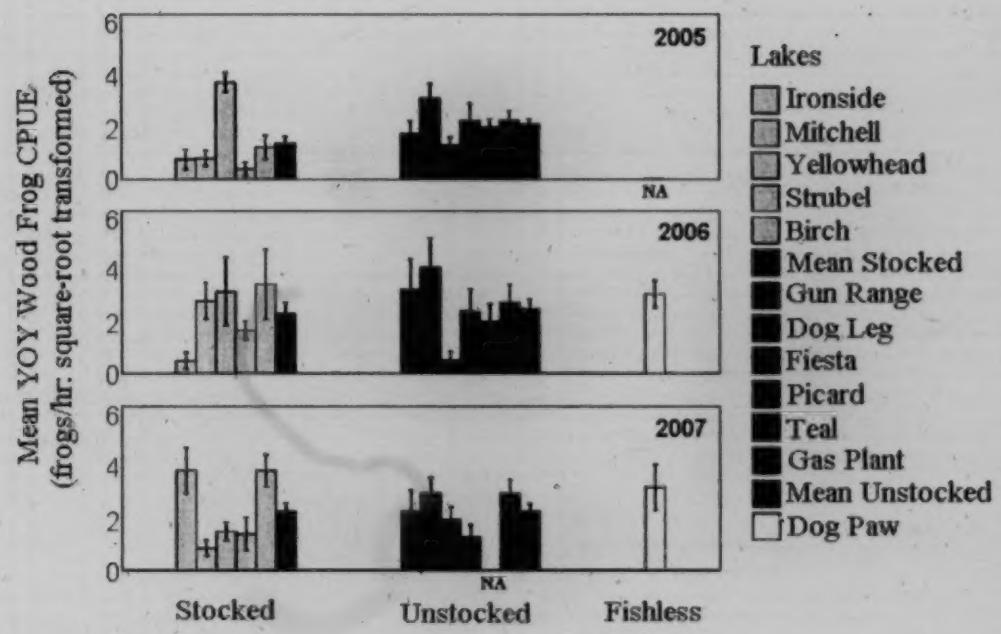



Figure 4. Mean catch-per-unit-effort (CPUE) of young-of-year (YOY) wood frogs caught along transects at 11 lakes (2005 and 2007) and 12 lakes (2006) within stocked, unstocked, and fishless treatments in the boreal foothills of Alberta. Lake means are calculated using sampling date as unit of replication. Bars represent the standard error of the mean. Split-plot ANOVA carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed with fish-bearing and fishless treatments. Reading lakes on x-axis left to right matches the legend from top to bottom. NA = lake not sampled that year.

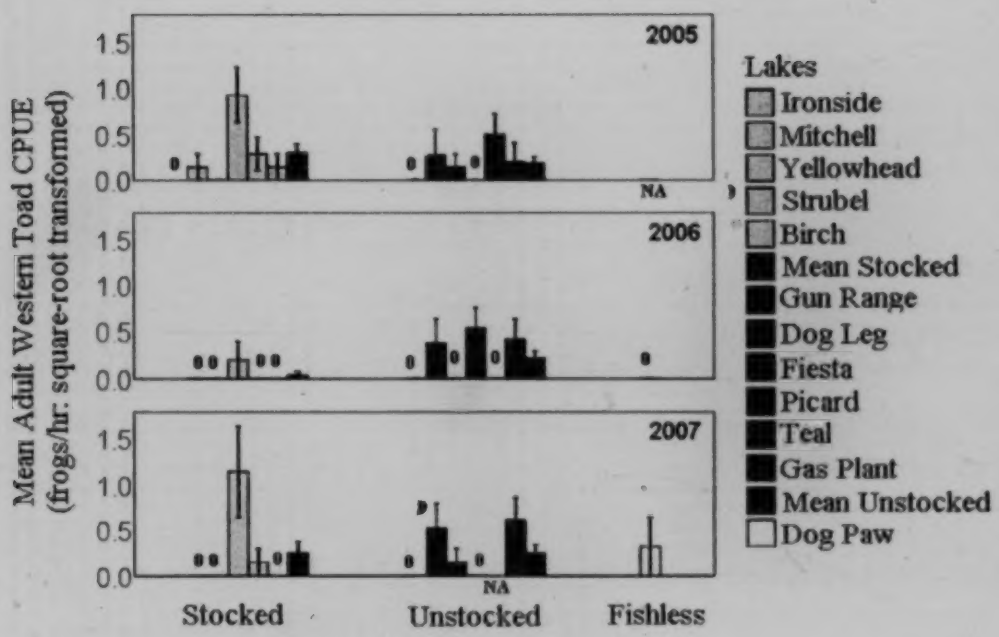



Figure 5. Mean catch-per-unit-effort (CPUE) of adult western toads caught along transects at 11 lakes (2005 and 2007) and 12 lakes (2006) within stocked, unstocked, and fishless treatments in the boreal foothills of Alberta. Lake means are calculated using sampling date as unit of replication. Bars represent the standard error of the mean. Split-plot ANOVA carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed with fish-bearing and fishless treatments. Reading lakes on x-axis left to right matches the legend from top to bottom. 0 = zero value. NA = lake not sampled that year.

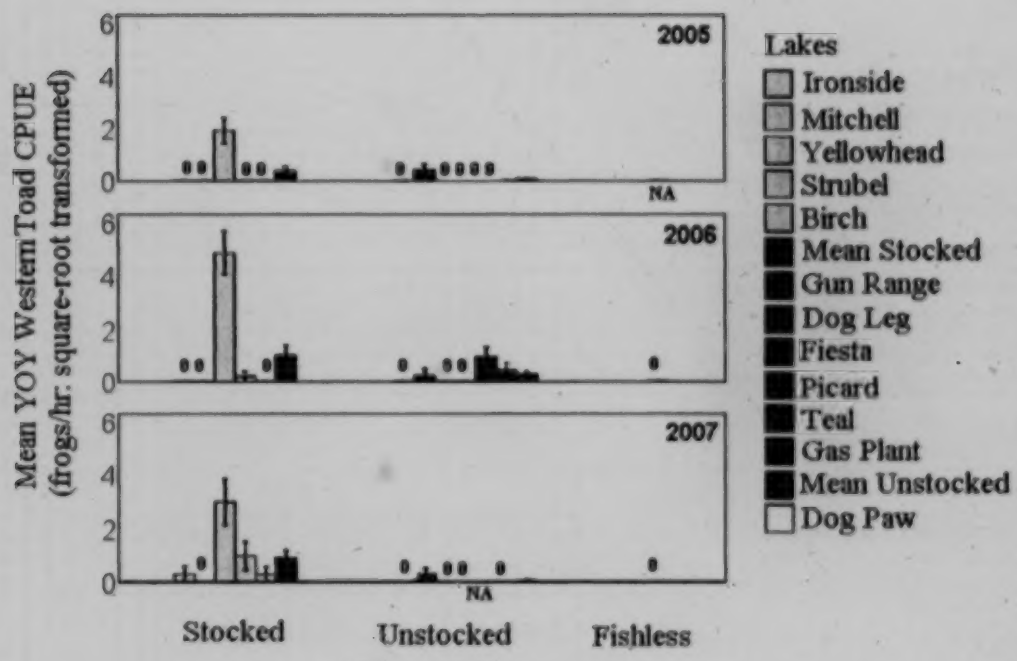



Figure 6. Mean catch-per-unit-effort (CPUE) of young-of-year western toads caught along transects at 11 lakes (2005 and 2007) and 12 lakes (2006) within stocked, unstocked, and fishless treatments in the boreal foothills of Alberta. Lake means are calculated using sampling date as unit of replication. Bars represent the standard error of the mean. Split-plot ANOVA carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed with fish-bearing and fishless treatments. Reading lakes on x-axis left to right matches the legend from top to bottom. 0 = zero value. NA = lake not sampled that year.

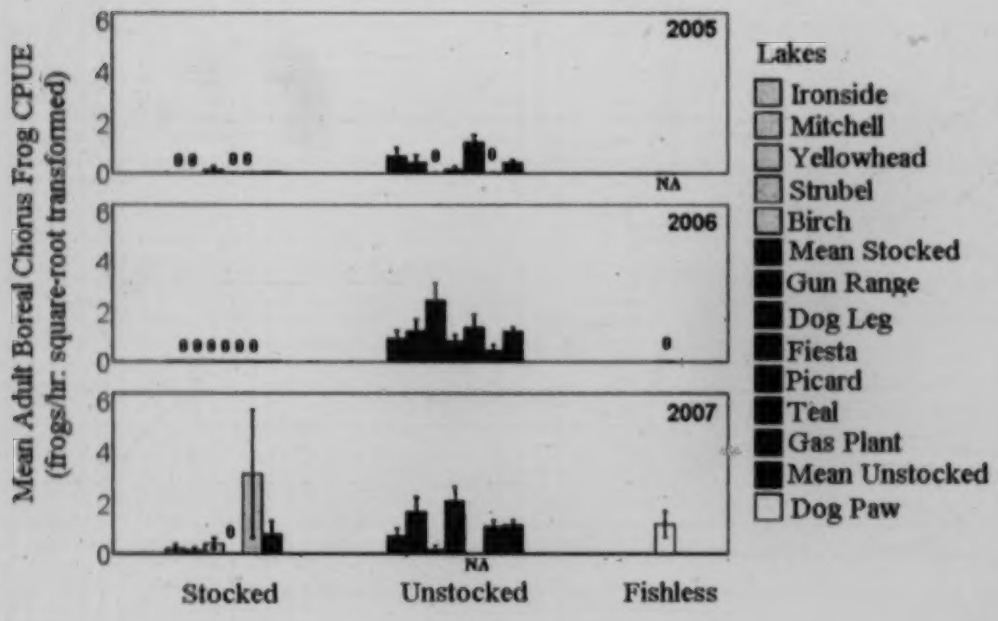



Figure 7. Mean catch-per-unit-effort (CPUE) of adult boreal chorus frogs caught along transects at 11 lakes (2005 and 2007) and 12 lakes (2006) within stocked, unstocked, and fishless treatments in the boreal foothills of Alberta. Lake means are calculated using sampling date as unit of replication. Bars represent the standard error of the mean. Split-plot ANOVA carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed with fish-bearing and fishless treatments. Reading lakes on x-axis left to right matches the legend from top to bottom. 0 = zero value. NA = lake not sampled that year.

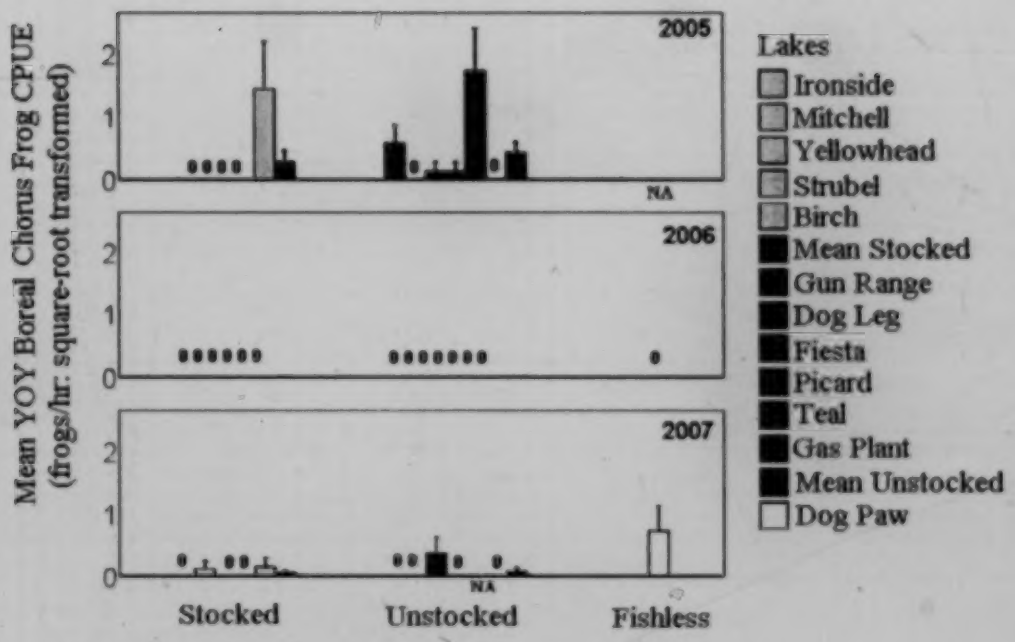



Figure 8. Mean catch-per-unit-effort (CPUE) of young-of-year (YOY) boreal chorus frogs caught along transects at 11 lakes (2005 and 2007) and 12 lakes within stocked, unstocked, and fishless treatments in the boreal foothills of Alberta. No YOY boreal chorus frogs were found in 2006. Lake means are calculated using sampling date as unit of replication. Bars represent the standard error of the mean. Split-plot ANOVA carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed with fish-bearing and fishless treatments. Reading lakes on x-axis left to right matches the legend from top to bottom. 0 = zero value. NA = lake not sampled that year.

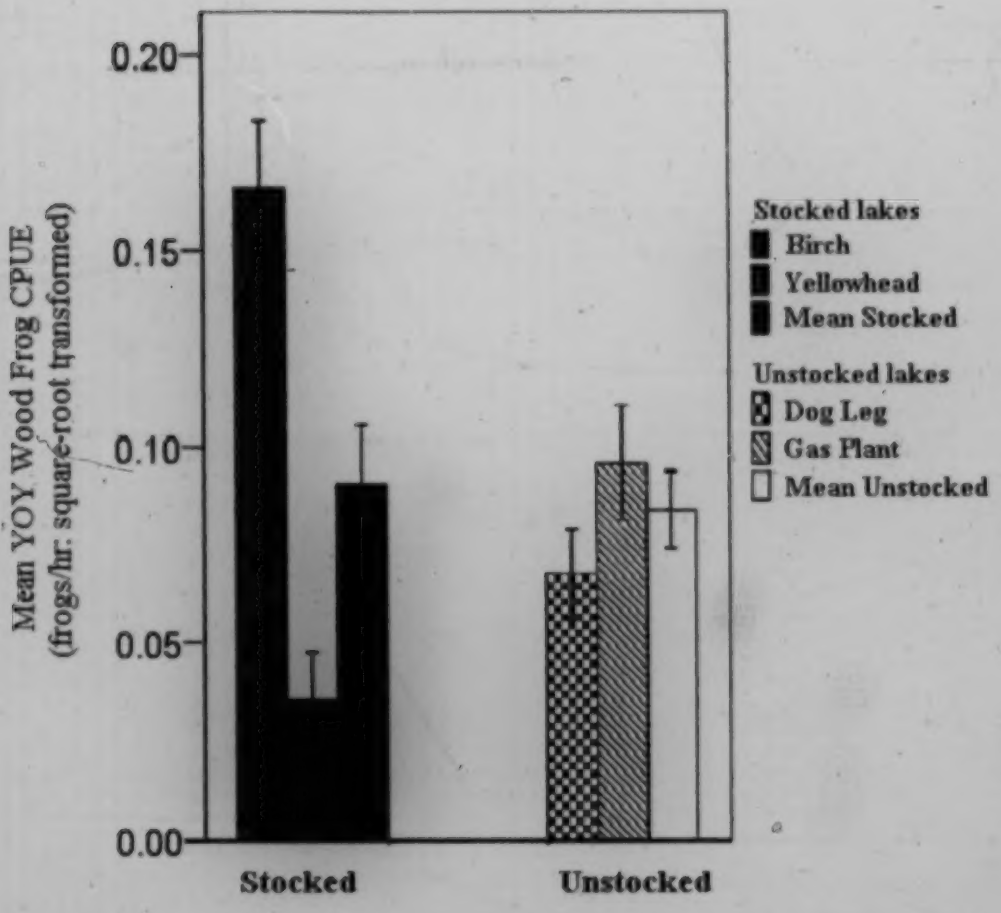



Figure 9. Mean catch-per-unit-effort (CPUE) of young-of-year (YOY) wood frog 2006 pitfall array traps from 2 stocked lakes (Birch and Yellowhead) and 2 unstocked lakes (Dog Leg and Gas Plant) in the boreal foothills of Alberta. Lake means are calculated using sampling date as unit of replication. Bars represent the standard error of the mean. Split-plot ANOVA was carried out on stocked and unstocked treatments. Reading lakes on x-axis left to right matches the legend from top to bottom. 0 = zero value. NA = lake not sampled that year.

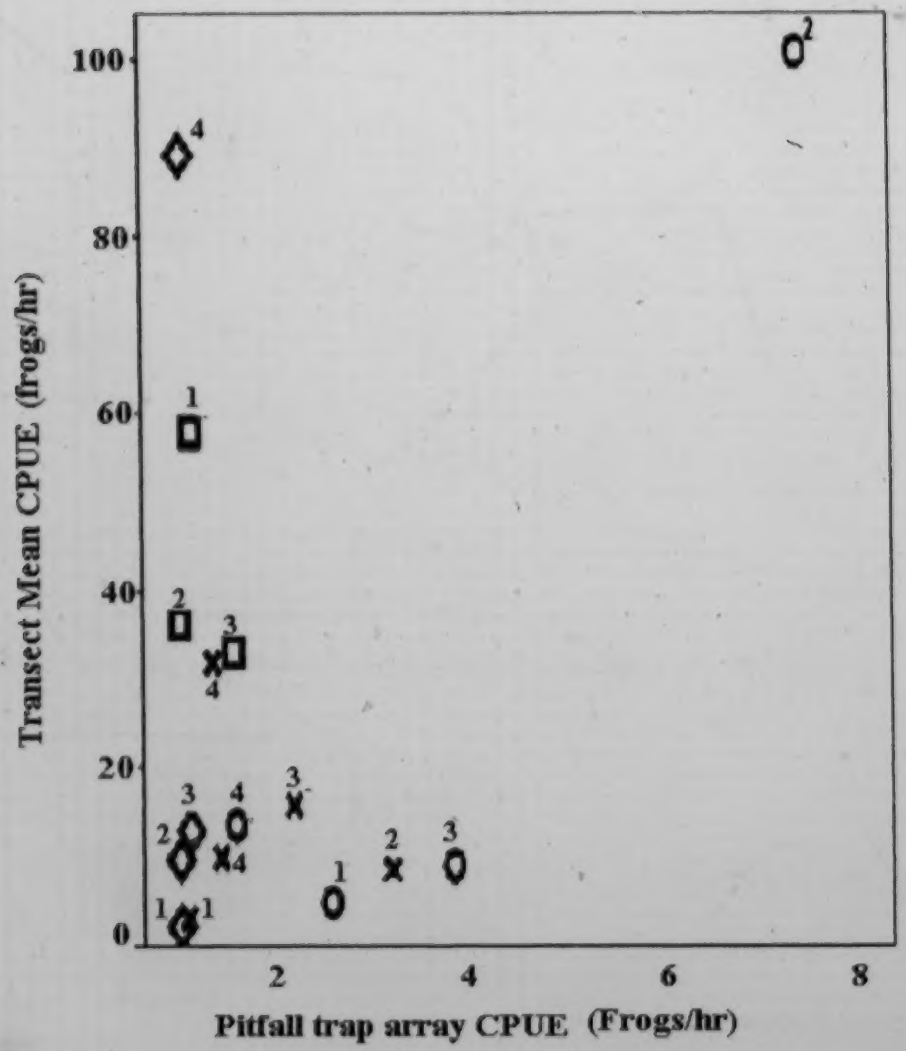



Figure 10. Scatter plot comparing young-of-year (YOY) wood frog CPUE transect and pitfall array traps (2006) survey estimates from 2 stocked lakes (Birch and Yellowhead) and 2 unstocked lakes (Dog Leg and Gas Plant) in the boreal foothills of Alberta. A Spearman's rho and regression ANOVA were conducted. CIRCLE = Birch lake, DIAMOND = Yellowhead Lake, CROSS = Gas Plant, SQUARE = Dog Leg. The number beside the letter corresponds to the sampling period.

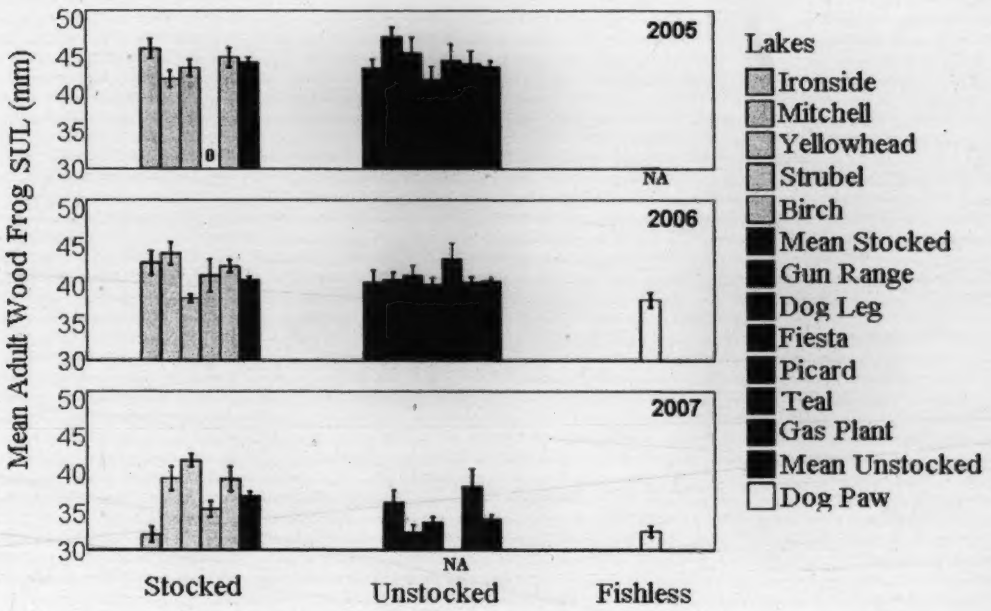



Figure 11. Mean snout-urostyle length (SUL) adult wood frogs captured along transect in 2006 at 12 lakes within fishless, stocked, and unstocked treatments in the boreal foothills of Alberta. Bars represent the standard error of the mean. Split-plot ANOVA carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed with fish-bearing and fishless treatments. Reading lakes on x-axis left to right matches the legend from top to bottom. NA = lake not sampled that year

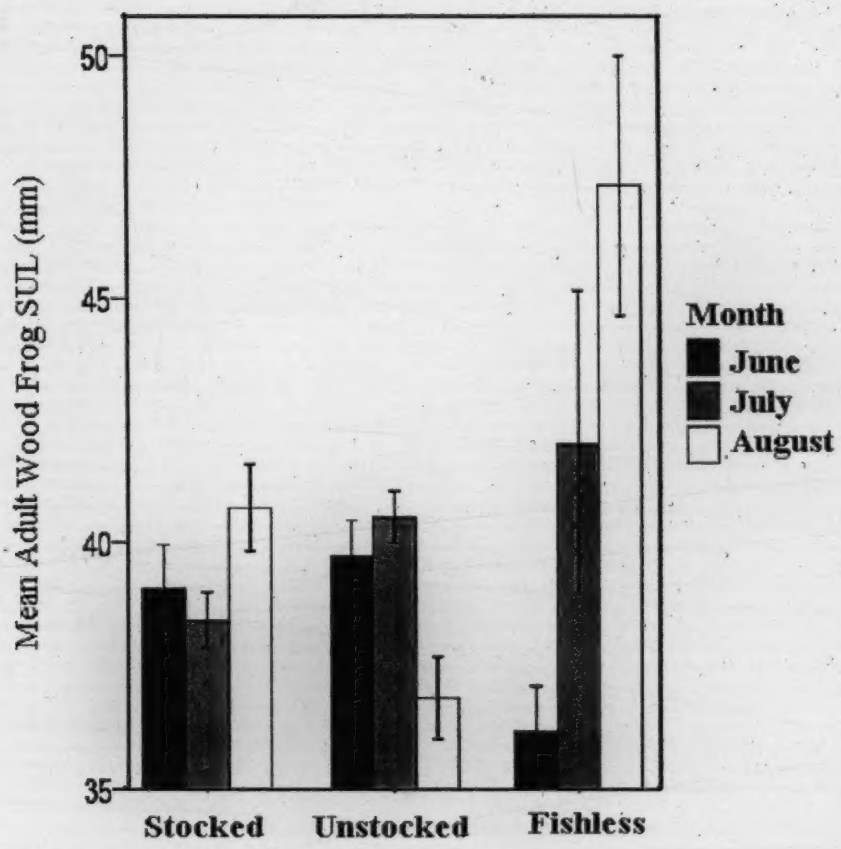



Figure 12. Mean snout-urostyle length (SUL) of adult wood frogs captured along transects in 2006 at 12 lakes within fishless, stocked, and unstocked treatments and months, in the boreal foothills of Alberta. Bars represent the standard error of the mean. Split-plot ANOVA carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed with fish-bearing and fishless treatments. Reading lakes on x-axis left to right matches the legend from top to bottom..

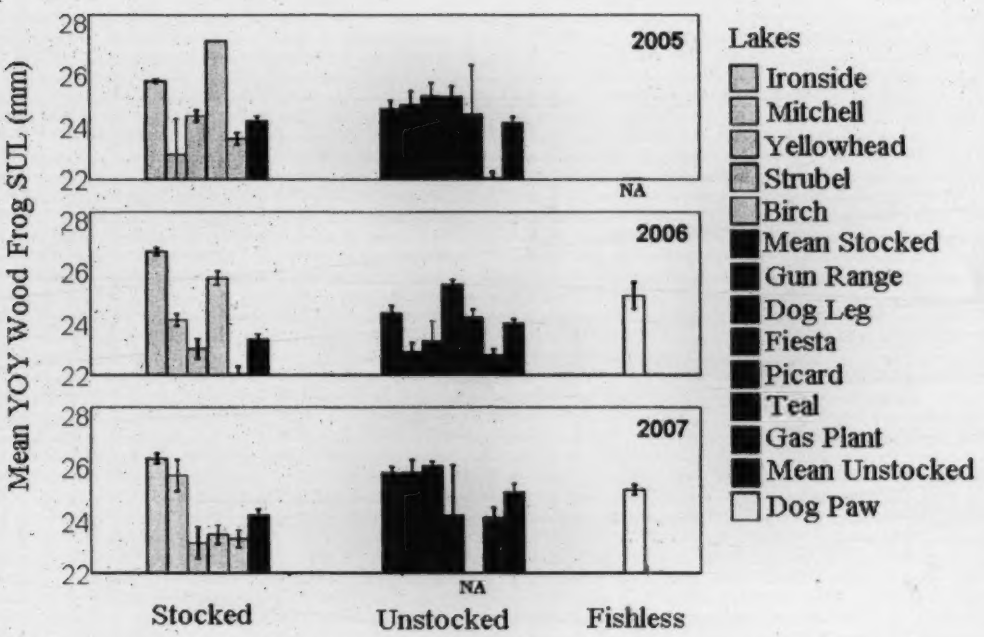



Figure 13. Mean snout-urostyle length (SUL) of young-of-year (YOY) wood frogs captured along transect in 2006 at 12 lakes within fishless, stocked, and unstocked treatments in the boreal foothills of Alberta. Bars represent the standard error of the mean. Split-plot ANOVA was carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed on fish-bearing treatment and the fishless lake. Reading lakes on the x-axis left to right matches the legend from top to bottom. NA = lake not sampled that year.

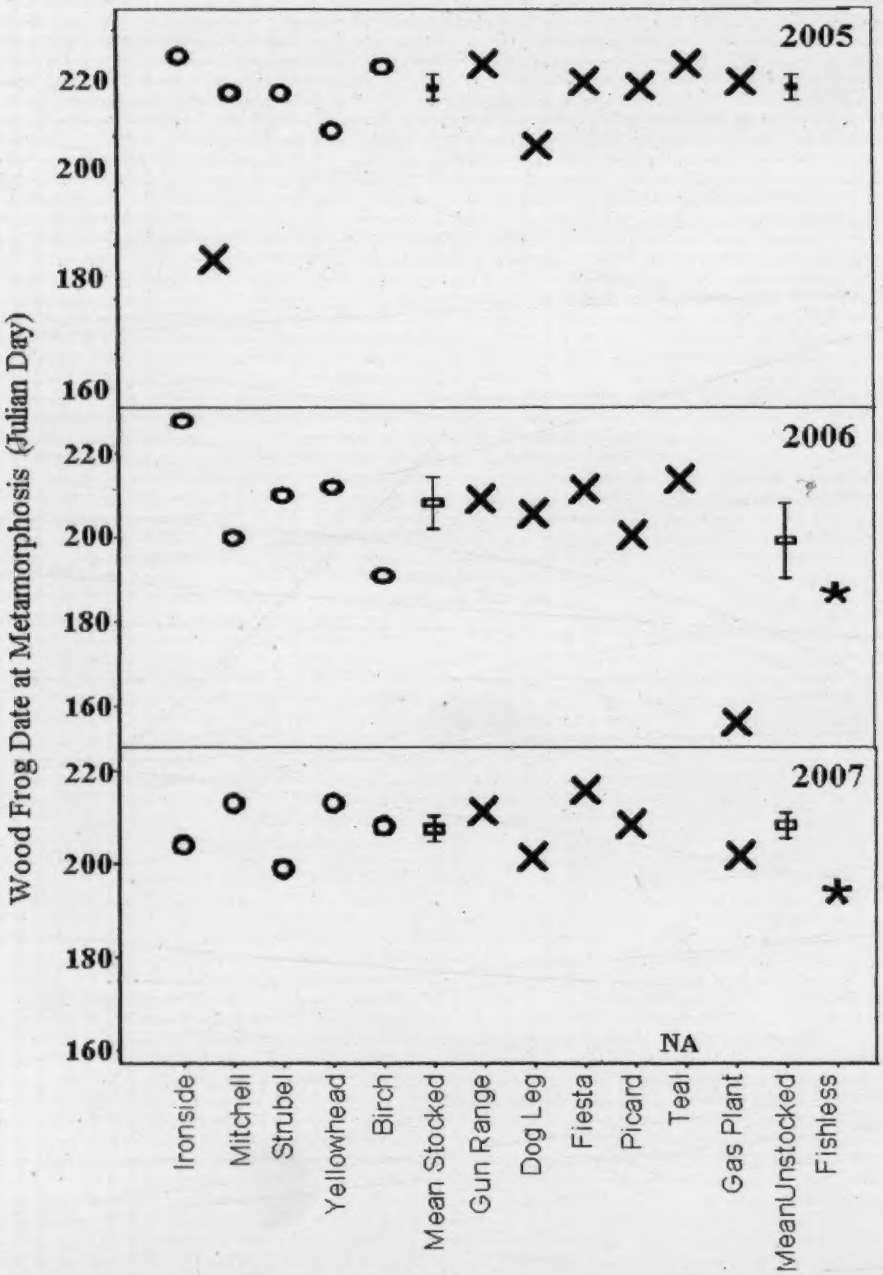



Figure 14. Julian date of metamorphosis for young-of-year (YOY) wood frogs in 2005, 2006, and 2007. Split-plot ANOVA was carried out on stocked and unstocked treatments and Comparison of a Single Observation with the Mean of a Sample test performed on fish-bearing treatment and the fishless lake. NA = lake not sampled that year. Circles are stocked lakes, crosses are unstocked lakes, rectangles are means of the treatments and star is the fishless lake. Bars represent the standard error of the mean.

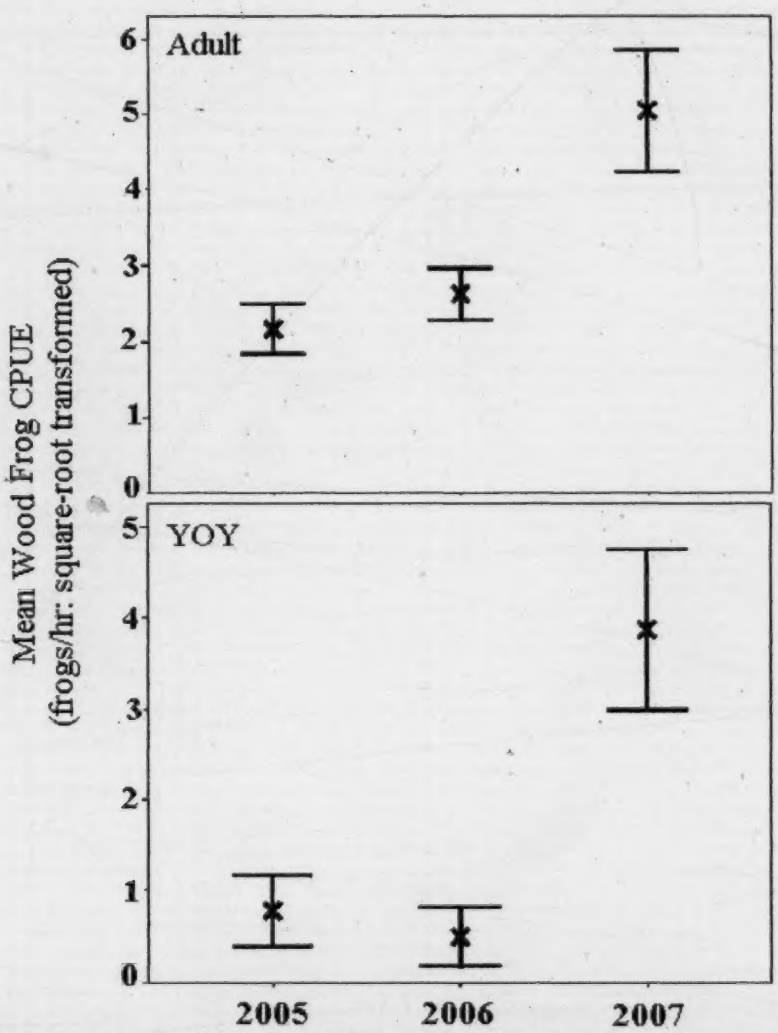



Figure 15. Mean catch-per-unit-effort (CPUE) for adult and young-of-year (YOY) wood frogs captured on Ironside's transect in 2005, 2006 and 2007 in the boreal foothills of Alberta. Lake means are calculated using sampling date as unit of replication. Bars represent the standard error of the mean. One-way ANOVAs were conducted comparing years.

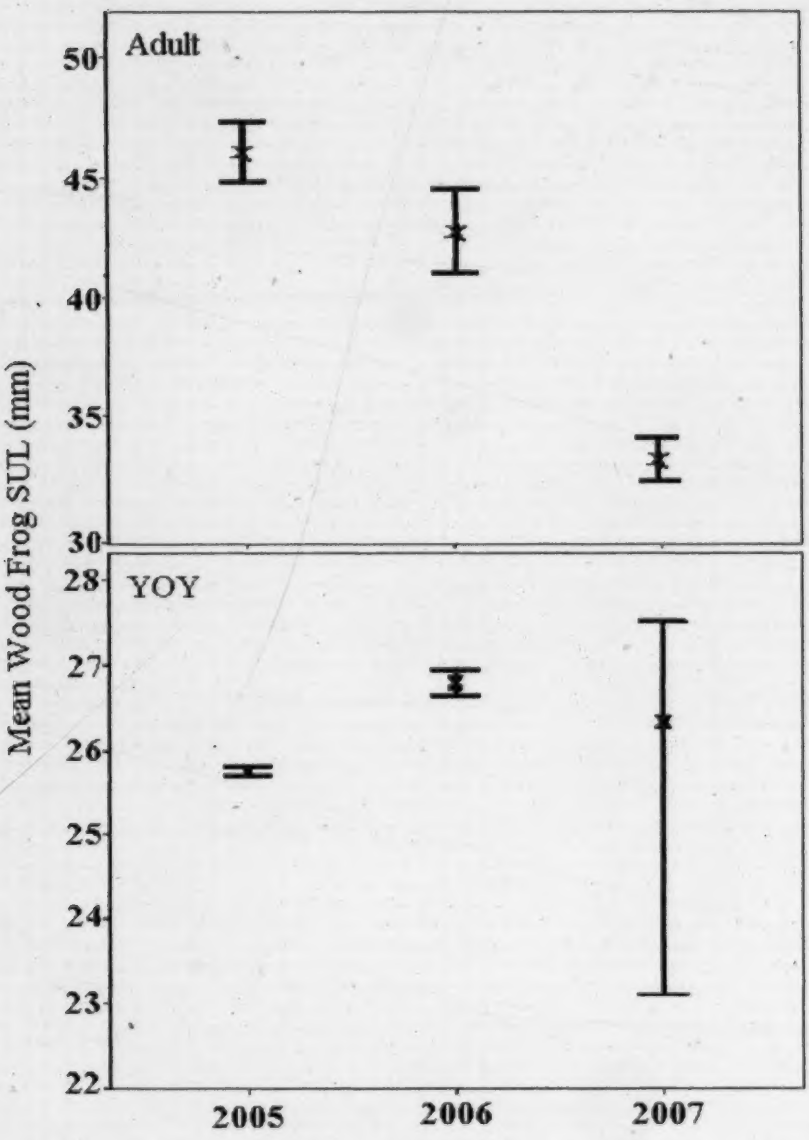
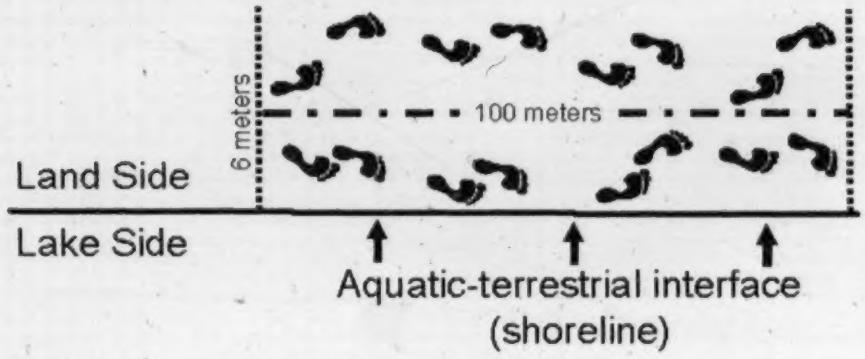
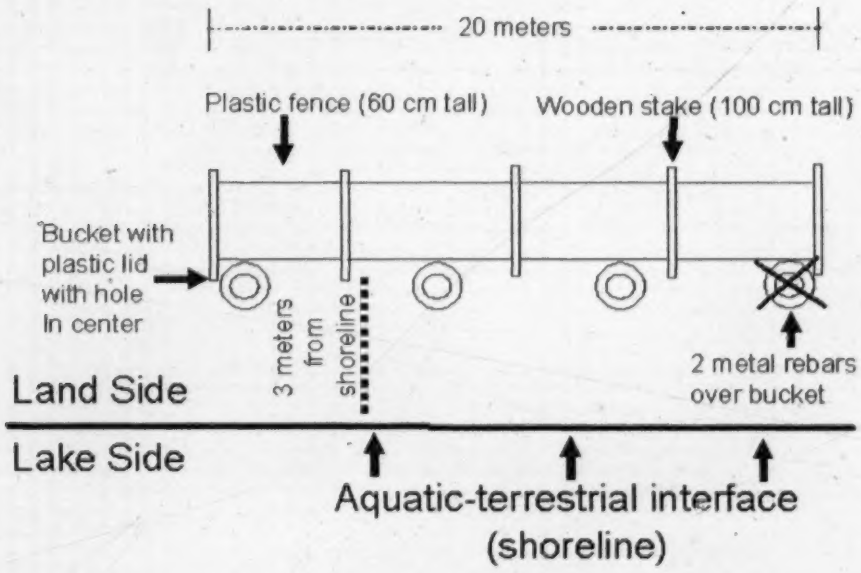



Figure 16. Mean snout-urostyle length (SUL) of adult and young-of-year (YOY) wood frogs captured on Ironside's transect in 2005, 2006 and 2007 in the boreal foothills of Alberta. Bars represent the standard error of the mean. One-way ANOVAs were conducted comparing years.

A) One 100-meter Transect Survey




B) One 20-meter Pitfall Array Trap




Appendix A. Two schematic diagrams. A) Transect Survey. Transects were 100 m in length and approximately 6 meters wide. Foot prints represent two surveyors walking parallel to each other in a zig-zag motion. B) Pitfall Trap Array. Stakes placed into ground (20 cm into ground, 80 cm above ground). Plastic fence is stretched from stake to stake and stapled. The height of the fence (height of plastic) was 60 cm high and an additional 15 cm sits on the ground and with soil placed on top hindering amphibians from passing under. On 2 lakes (Gas Plant and Dog Leg) with cattle, two 1 m long metal rebars (bent into horseshoe shapes) were placed over every bucket in a cross formation and pushed into the ground. Rebar halted cattle from stepping into buckets and injuring themselves.

Appendix B. Table showing raw wood frog call survey data for 2006. Each lake was surveyed once in each sampling period (Sampling period 1: April 24th to April 27th; Sampling period 2: May 2nd to May 5th; Sampling period 3: May 6th to May 13th). For all point counts for a given lake, the number of groups for each Rank was summed. The possibility of having more number of call codes heard at a point count exists because surveyors where able to distinguish multiple groups of calling males at a single point count.

| Sampling Period | LAKE | No. of Point Counts | Call Code Index | | | |
|---|---|---|---|---|---|---|
| | | | RANK 0 | RANK 1 | RANK 2 | RANK 3 |
| 1 | Ironside | 2 | 1 | 1 | 0 | 0 |
| | Mitchell | 3 | 2 | 1 | 0 | 0 |
| | Yellowhead | 4 | 1 | 0 | 0 | 3 |
| | Strubel | 3 | 3 | 0 | 0 | 0 |
| | Birch | 5 | 1 | 1 | 2 | 1 |
| | Gun Range | 2 | 1 | 1 | 0 | 0 |
| | Dog Leg | 3 | 0 | 0 | 0 | 3 |
| | Fiesta | 4 | 2 | 2 | 0 | 0 |
| | Picard | 4 | 1 | 3 | 1 | 0 |
| | Teal | 5 | 3 | 1 | 0 | 1 |
| | Gas Plant | 5 | 1 | 1 | 1 | 2 |
| 2 | Ironside | 2 | 1 | 1 | 0 | 0 |
| | Mitchell | 3 | 3 | 0 | 0 | 0 |
| | Yellowhead | 4 | 0 | 7 | 0 | 4 |
| | Strubel | 3 | 3 | 0 | 0 | 0 |
| | Birch | 6 | 1 | 4 | 1 | 0 |
| | Gun Range | 2 | 0 | 2 | 0 | 0 |
| | Dog Leg | 3 | 2 | 0 | 1 | 0 |
| | Fiesta | 4 | 4 | 0 | 0 | 0 |
| | Picard | 4 | 2 | 2 | 0 | 0 |
| | Teal | 5 | 1 | 4 | 1 | 0 |
| | Gas Plant | 5 | 0 | 4 | 2 | 1 |
| 3 | Ironside | 2 | 1 | 1 | 0 | 0 |
| | Mitchell | 3 | 1 | 1 | 1 | 0 |
| | Yellowhead | 4 | 3 | 1 | 0 | 0 |
| | Strubel | 3 | 1 | 3 | 0 | 0 |
| | Birch | 6 | 6 | 0 | 0 | 0 |
| | Gun Range | 2 | 1 | 1 | 0 | 0 |
| | Dog leg | 3 | 2 | 1 | 0 | 0 |
| | Fiesta | 4 | 4 | 0 | 0 | 0 |
| | Picard | 4 | 4 | 0 | 0 | 0 |
| | Teal | 5 | 4 | 1 | 0 | 0 |
| | Gas Plant | 5 | 3 | 2 | 0 | 0 |

Appendix C. Presence/absence of adult and young-of-year wood frog, boreal chorus frog, western toad in transect surveys and pitfall traps during the same survey period (July 17th till August 17th) in 2006. Y = at least one individual in that age class was seen. N = no individuals in the age class were seen.

| Method | Lake | Wood frog | | Boreal chorus frog | | Western toad | |
|---|---|---|---|---|---|---|---|
| | | A | YOY | A | YOY | A | YOY |
| Transect | Yellowhead | Y | Y | N | N | N | Y |
| | Birch | Y | Y | N | N | N | N |
| | Dog leg | Y | Y | Y | N | Y | Y |
| | Gas Plant | Y | Y | Y | N | Y | Y |
| Pitfall | Yellowhead | Y | Y | Y | N | Y | Y |
| | Birch | Y | Y | Y | N | N | N |
| | Dog leg | Y | Y | Y | Y | Y | Y |
| | Gas Plant | Y | Y | Y | N | Y | Y |

Appendix D. Number of adult male and female wood frogs, boreal chorus frogs and western toad seen in 2006 pitfall trap arrays, over the entire summer. Numbers for young-of-year (YOY) wood frogs, boreal chorus frogs, and western toads are also included. N/A represents individuals seen but not captured.

| Age | Species&Sex | Birch | Yellowhead | Dog Leg | Gas Plant |
|---|---|---|---|---|---|
| Adult | Wood frog | | | | |
| | Male | 45 | 21 | 60 | 49 |
| | Female | 13 | 13 | 15 | 19 |
| | N/A | 0 | 32 | 0 | 0 |
| | Boreal Chorus Frog | | | | |
| | Male | 1 | 1 | 5 | 4 |
| | Female | 4 | 1 | 8 | 2 |
| | N/A | 1 | 0 | 3 | 0 |
| | Western Toad | | | | |
| | Male | 2 | 4 | 2 | 5 |
| | Female | 1 | 1 | 1 | 1 |
| | N/A | 0 | 0 | 1 | 0 |
| YOY | Wood Frog | 263 | 6 | 30 | 85 |
| | Boreal Chorus Frog | 0 | 0 | 0 | 0 |
| | Western Toad | 0 | 90 | 120 | 2 |

Appendix E. Adult and young-of-year (YOY) wood frog mean ± standand error (SE) snout-urostyle length (SUL: mm) for each lake in 2005, 2006, and 2007, for the same sampling period (July 16th – August 15th). Adult SUL mean ± SE come from all individuals measured on transects, while YOY mean ± SE is calculated from the 1st 30 individuals caught (or less than 30 at lakes where 30 individuals were not obtained) on transects. A dashed line represents no data. Numbers in parenthesis is the sample size.

| Age | Lake | 2005 Mean | ± SE | 2006 Mean | ± SE | 2007 Mean | ± SE |
|---|---|---|---|---|---|---|---|
| Adult | | | | | | | |
| | Ironside | 46.0 | 1.35 (12) | 42.9 | 2.71 (01) | 30.8 | 2.26 (03) |
| | Mitchell | 40.8 | 1.16 (07) | 44.1 | 2.27 (17) | 38.4 | 1.57 (11) |
| | Strubel | - | - | 36.4 | 2.28 (14) | 34.8 | 1.53 (15) |
| | Yellowhead | 42.6 | 1.24 (22) | 38.0 | 0.55 (95) | 40.4 | 1.03 (39) |
| | Birch | 45.6 | 1.81 (02) | 38.6 | 0.99 (79) | 42.0 | 2.43 (07) |
| | Gun Range | 40.1 | 1.51 (24) | 37.6 | 1.94 (20) | 29.4 | 0.44 (07) |
| | Dog Leg | 46.7 | 1.29 (05) | 38.8 | 1.14 (62) | 42.3 | 7.45 (02) |
| | Fiesta | 44.7 | 2.25 (05) | 37.4 | 1.78 (14) | 40.3 | 2.22 (05) |
| | Picard | 41.8 | 1.81 (20) | 38.2 | 1.82 (21) | 38.9 | 1.47 (20) |
| | Teal | 39.2 | 2.79 (05) | 31.9 | 2.03 (10) | - | - |
| | Gas Plant | 44.8 | 1.95 (04) | 36.1 | 0.72 (102) | 42.4 | 2.31 (02) |
| | Dog Paw | - | - | 40.9 | 2.54 (10) | 43.2 | 0.81 (09) |
| YOY | | | | | | | |
| | Ironside Pond | 25.8 | 0.06 (02) | 26.8 | 0.15 (02) | 26.34 | 0.19 (30) |
| | Mitchell | 22.9 | 1.36 (02) | 24.2 | 0.23 (30) | 25.7 | 0.59 (06) |
| | Strubel | 27.3 | (01) | 25.8 | 0.27 (08) | 23.48 | 0.35 (23) |
| | Yellowhead | 24.4 | 0.20 (30) | 23.0 | 0.39 (26) | 23.16 | 0.60 (27) |
| | Birch | 23.5 | 0.23 (14) | 22.0 | 0.38 (28) | 23.31 | 0.33 (30) |
| | Gun Range | 24.7 | 0.34 (15) | 24.4 | 0.27 (30) | 25.78 | 0.33 (22) |
| | Dog Leg | 24.9 | 0.51 (12) | 22.9 | 0.35 (25) | 24.79 | 0.24 (5) |
| | Fiesta | 25.2 | 0.52 (04) | 23.3 | 0.79 (02) | 26.06 | 0.49 (22) |
| | Picard | 25.1 | 0.41 (17) | 25.5 | 0.18 (27) | 24.19 | 0.16 (14) |
| | Teal | 24.5 | 1.88 (03) | 24.2 | 0.32 (19) | - | - |
| | Gas Plant | 22.1 | 0.22 (18) | 22.8 | 0.24 (21) | 24.11 | 0.36 (30) |
| | Dog Paw | - | - | 25.1 | 0.52 (09) | 25.15 | 0.18 (28) |

Appendix F. Presence/absence data for adult and young-of-year (YOY) wood frog, boreal chorus frog, and western toad from transect surveys. Y = at least one individual in that age class was seen. N = no individual in the age class was seen. Dashed line = lake was not surveyed that year.

| Age | Lake | Wood Frog | | | Boreal Chorus Frog | | | Western Toad | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 |
| Adult | | | | | | | | | | |
| | Ironside Pond | Y | Y | Y | N | N | Y | Y | N | N |
| | Mitchell | Y | Y | Y | N | N | Y | Y | N | Y |
| | Strubel | Y | Y | Y | N | N | N | Y | Y | Y |
| | Yellowhead | Y | Y | Y | Y | N | Y | Y | Y | Y |
| | Birch | Y | Y | Y | N | N | Y | Y | N | N |
| | Gun Range | Y | Y | Y | Y | Y | Y | N | N | N |
| | Dog Leg | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| | Fiesta | Y | Y | Y | N | Y | Y | Y | N | Y |
| | Picard | Y | Y | Y | Y | Y | Y | N | Y | N |
| | Teal | Y | Y | - | Y | Y | - | Y | N | - |
| | Gas Plant | Y | Y | Y | N | Y | Y | Y | Y | Y |
| | Dog Paw | - | Y | Y | - | N | Y | - | N | N |
| YOY | | | | | | | | | | |
| | Ironside Pond | Y | Y | Y | N | N | N | N | N | Y |
| | Mitchell | Y | Y | Y | N | N | Y | N | N | N |
| | Strubel | Y | Y | Y | N | N | N | Y | Y | Y |
| | Yellowhead | Y | Y | Y | N | N | N | Y | Y | Y |
| | Birch | Y | Y | Y | Y | N | Y | N | N | Y |
| | Gun Range | Y | Y | Y | Y | N | N | N | N | N |
| | Dog Leg | Y | Y | Y | N | N | N | Y | Y | Y |
| | Fiesta | Y | Y | Y | Y | N | Y | N | N | N |
| | Picard | Y | Y | Y | Y | N | N | N | N | Y |
| | Teal | Y | Y | - | Y | N | - | N | Y | - |
| | Gas Plant | Y | Y | Y | N | N | N | N | Y | N |
| | Dog Paw | - | Y | Y | - | N | N | - | N | N |

Appendix G. Number of adult female and male wood frogs seen throughout the entire summer for 2005, 2006, and 2007. Numbers come from transect surveys. These numbers do not precisely correspond to total adult wood frogs seen because they do not include animals that were lost and therefore could not be sexed. A dashed line represents no data.

| Lake | 2005 | | 2006 | | 2007 | |
|---|---|---|---|---|---|---|
| | Female | Male | Female | Male | Female | Male |
| Ironside Pond | 6 | 6 | 4 | 3 | 5 | 1 |
| Mitchell | 0 | 5 | 8 | 1 | 8 | 8 |
| Strubel | 0 | 0 | 1 | 5 | 8 | 10 |
| Yellowhead | 10 | 9 | 9 | 14 | 16 | 21 |
| Birch | 1 | 1 | 11 | 5 | 9 | 7 |
| Gun Range | 9 | 6 | 9 | 8 | 0 | 3 |
| Dog Leg | 4 | 1 | 4 | 3 | 7 | 3 |
| Fiesta | 3 | 2 | 0 | 4 | 4 | 1 |
| Picard | 9 | 5 | 9 | 4 | 6 | 9 |
| Teal | 2 | 2 | 2 | 1 | - | - |
| Gas Plant | 3 | 2 | 8 | 2 | 4 | 4 |
| Dog Paw | - | - | 3 | 2 | 2 | 3 |

Appendix H -1. Adult and young-of-year (YOY) wood frog (WF), western toad (WT), and boreal chorus frog (BCF) mean catch-per-unit-effort (CPUE: frogs/hr) of all visual transects for each lake in 2005. Eack sampling period is represented even if it was not included in analyses. Each lake was only visited once during each sampling period. Each period extended from the date given in the column to the day before the next column date (i.e., 16-July to 20-July, 21-July to 24-July).

| AGE | SPECIES | LAKE | PERIOD | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 16-Jul | 21-Jul | 25-Jul | 29-Jul | 2-Aug | 5-Aug |
| ADULT | WF | Ironside | 9.7 | 8.4 | 4.5 | 8.2 | 5.3 | 5.8 |
| | | Mitchell | 1.5 | 6.7 | 4.5 | 14.8 | 0 | 0.8 |
| | | Strubel | 26.1 | 7.9 | 7.5 | 5.2 | 11.2 | 11 |
| | | Yellowhead | 2.3 | 0 | 0.8 | 0 | 0.8 | 1.5 |
| | | Birch | 0 | 10.4 | 6.7 | 3 | 7.5 | 3 |
| | | Gun Range | 17.1 | 13.2 | 16.3 | 8.9 | 7.4 | 9.7 |
| | | Dog Leg | 6.8 | 10.4 | 5.2 | 0.7 | 9.7 | 3.8 |
| | | Fiesta | 8.2 | 3 | 2.3 | 1.5 | 3.7 | 1.5 |
| | | Picard | 0 | 0 | 4 | 8.2 | 8.1 | 13.5 |
| | | Teal | 14.8 | 1 | 1 | 1 | 1 | 1 |
| | | Gas Plant | 0.6 | 0.7 | 0.7 | 3 | 2.2 | 9.7 |
| | WT | Ironside | 0.8 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 0.8 | 0.8 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 2.2 | 1.5 | 2.2 | 2 | 0 | 0 |
| | | Birch | 0.8 | 0 | 0 | 0 | 0 | 0 |
| | | Gun Range | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Leg | 2.8 | 0 | 0 | 0 | 0 | 0 |
| | | Fiesta | 0.7 | 0 | 0 | 0 | 0 | 0 |
| | | Picard | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Teal | 1 | 1 | 1 | 0 | 0 | 0 |
| | | Gas Plant | 1.5 | 0 | 0 | 0 | 0 | 0 |

Appendix H – 1 continued

| AGE | SPECIES | LAKE | PERIOD | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 16-Jul | 21-Jul | 25-Jul | 29-Jul | 2-Aug | 5-Aug |
| ADULT | BCF | Ironside | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 0.7 | 0 | 0 | 0 | 0 | 0 |
| | | Birch | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gun Range | 3 | 0.7 | 2.3 | 0 | 0 | 0 |
| | | Dog Leg | 0.8 | 2.9 | 0 | 0 | 0 | 0 |
| | | Fiesta | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Picard | 0.8 | 0 | 0 | 0 | 0 | 0 |
| | | Teal | 2 | 2 | 4 | 1 | 2.6 | 0 |
| | | Gas Plant | 0 | 0 | 0 | 0 | 0 | 0 |
| YOY | WF | Ironside | 0.7 | 4.5 | 2.9 | 0 | 0 | 0 |
| | | Mitchell | 3.7 | 0.8 | 0.8 | 1.5 | 0 | 0 |
| | | Strubel | 5.5 | 21.7 | 13.4 | 11.2 | 22.7 | 13.2 |
| | | Yellowhead | 1.5 | 1.5 | 0 | 0 | 0 | 0 |
| | | Birch | 0.7 | 6.8 | 4.5 | 3.8 | 0 | 0 |
| | | Gun Range | 1.5 | 3 | 3 | 10.4 | 8.2 | 0 |
| | | Dog Leg | 5.7 | 22.5 | 9 | 1.5 | 20.9 | 8.2 |
| | | Fiesta | 2.3 | 3.7 | 1.5 | 4.5 | 1.4 | 0 |
| | | Picard | 2.2 | 5.2 | 15.7 | 16.5 | 3.7 | 0 |
| | | Teal | 4 | 2 | 2 | 10.9 | 1.9 | 7 |
| | | Gas Plant | 4.7 | 8.9 | 12.7 | 4.5 | 2.2 | 2.3 |
| | WT | Ironside | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 1.6 | 13.1 | 5 | 5 | 4.5 | 0 |
| | | Birch | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gun Range | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Leg | 0.8 | 0.8 | 0.8 | 0 | 0 | 0 |
| | | Fiesta | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Picard | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Teal | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gas Plant | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix H – 1 continued

| AGE | SPECIES | LAKE | PERIOD | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 16-Jul | 21-Jul | 25-Jul | 29-Jul | 2-Aug | 5-Aug |
| BCF | | Ironside | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 0.7 | 0 | 0 | 0 | 0 | 0 |
| | | Birch | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gun Range | 3 | 0.7 | 2.3 | 0 | 0 | 0 |
| | | Dog Leg | 0.8 | 2.9 | 0 | 0 | 0 | 0 |
| | | Fiesta | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Picard | 0.8 | 0 | 0 | 0 | 0 | 0 |
| | | Teal | 2 | 2 | 4 | 1 | 2.6 | 0 |
| | | Gas Plant | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix H - 2. Adult and young-of-year (YOY) wood frog (WF), western toad (WT), and boreal chorus frog (BCF) mean catch-per-unit-effort (CPUE: frogs/hr) for all visual transects (2-6 transects) for each lake in 2006. Eack sampling period is represented even if it was not included in analyses. Each lake was only visited once during each sampling period. Each period extended from the date given in the column to the day before the next column date (i.e., 04-July to 10-July, 11-July to 17-July).

| AGE | SPECIES | LAKE | PERIOD | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 4-Jun | 11-Jun | 18-Jun | 25-Jun | 2-Jul | 9-Jul | 16-Jul | 23-Jul | 30-Jul | 6-Aug |
| ADULT | WF | Ironside | 3.6 | 9 | 21.4 | 2.9 | 5.8 | 5.8 | 10.3 | 11.3 | 1.5 | 6 |
| | | Mitchell | 6.9 | 1.5 | 5 | 6.1 | 1.5 | 12.1 | 2.9 | 6.8 | 7.5 | 8.2 |
| | | Strubel | 27.8 | 21.4 | 20 | 17.2 | 24.7 | 16.6 | 16.9 | 19.6 | 9 | 4.8 |
| | | Yellowhead | 3.9 | 5 | 1.8 | 1.5 | 4.4 | 9.1 | 8.9 | 7.5 | 8.2 | 2.3 |
| | | Birch | 16 | 20.4 | 8 | 9.1 | 11.9 | 7.6 | 13.7 | 6.9 | 14.4 | 14 |
| | | Gun Range | 9.9 | 4.2 | 9.8 | 4.1 | 6 | 8 | 12 | 11.9 | 6.7 | 9.7 |
| | | Dog Leg | 41 | 22.9 | 12 | 8 | 13.9 | 13.9 | 11.5 | 8.3 | 4 | 4.3 |
| | | Fiesta | 2 | 6.6 | 3.6 | 1.9 | 1.9 | 11.9 | 13.7 | 5.5 | 11 | 4 |
| | | Picard | 26.6 | 26.4 | 23.3 | 6 | 14.4 | 15 | 11.9 | 6.7 | 5.2 | 10.4 |
| | | Teal | 2.3 | 6.2 | 2.4 | 4.7 | 8.2 | 1.2 | 3.1 | 10.8 | 4.2 | 3.6 |
| | | Gas Plant | 5.9 | 5.3 | 12.8 | 4.8 | 12 | 6.8 | 12.6 | 11 | 14.6 | 21.9 |
| | | Dog Paw | 40.8 | 24 | 11.8 | 15.3 | 15 | 17.7 | 20.1 | 8.9 | 2.9 | |
| | WT | Ironside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 1.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 1.2 | 1.2 | 3.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Birch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gun Range | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Leg | 4.8 | 5.8 | 4.1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Fiesta | 4.7 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix H – 2 contiuned.

| AGE | SPECIES | LAKE | PERIOD | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 4-Jun | 11-Jun | 18-Jun | 25-Jun | 2-Jul | 9-Jul | 16-Jul | 23-Jul | 30-Jul | 6-Aug |
| YOY | WT | Picard | 1.2 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 0 | 0 | 0 | 0 |
| | | Teal | 2.3 | 1.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gas Plant | 1.2 | 1.2 | 1.2 | 2.4 | 1.3 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Paw | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | BCF | Ironside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 1.2 | 2.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Birch | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gun Range | 9.4 | 6.1 | 3.3 | 2 | 1.8 | 6 | 2 | 0 | 0 | 0 |
| | | Dog Leg | 36.8 | 34.6 | 8 | 13 | 2 | 1.9 | 4 | 0 | 0 | 0 |
| | | Fiesta | 26.6 | 30.7 | 15.8 | 21.9 | 25.1 | 13.9 | 9.6 | 2.2 | 0 | 0 |
| | | Picard | 41.5 | 0 | 1.5 | 1.5 | 2.2 | 2.9 | 2.9 | 0 | 0 | 0 |
| | | Teal | 18.7 | 15.7 | 1.2 | 3.6 | 15.4 | 12.9 | 3.6 | 0 | 0 | 0 |
| | | Gas Plant | 1.5 | 1.2 | 3.6 | 1.2 | 1 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Paw | 2.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| YOY | WF | Ironside | 0 | 0 | 0 | 0 | 1.5 | 3 | 0 | 0 | 0 | 0 |

Appendix I – 2 contiuned.

| AGE | SPECIES | LAKE | PERIOD | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 4-Jun | 11-Jun | 18-Jun | 25-Jun | 2-Jul | 9-Jul | 16-Jul | 23-Jul | 30-Jul | 6-Aug |
| YOY | WF | Mitchell | 0 | 0 | 0 | 0 | 9.1 | 6 | 28.1 | 13.5 | 5.9 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 1.2 | 1.2 | 1.2 | 8.7 | 11.9 | 4.8 |
| | | Yellowhead | 0 | 0 | 0 | 0 | 3 | 4.6 | 2.3 | 4.7 | 5.9 | 0 |
| | | Birch | 0 | 0 | 0 | 0 | 0.5 | 4.9 | 3.9 | 99.9 | 8 | 8.9 |
| | | Gun Range | 0 | 0 | 0 | 0 | 48.7 | 18.6 | 23.2 | 12.2 | 0 | 0 |
| | | Dog Leg | 0 | 0 | 0 | 0 | 3.9 | 56.8 | 35.3 | 32 | 12.5 | 0 |
| | | Fiesta | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 |
| | | Picard | 0 | 0 | 0 | 0 | 13.5 | 14.8 | 24 | 4.4 | 0 | 0 |
| | | Teal | 0 | 0 | 0 | 0 | 8.4 | 10.8 | 11.1 | 7.2 | 0 | 0 |
| | | Gas Plant | 0 | 0 | 0 | 0 | 3.5 | 1.2 | 2.2 | 7.5 | 14.7 | 9.5 |
| | | Dog Paw | 0 | 0 | 0 | 0 | 29.9 | 9 | 3 | 11.4 | 6 | 5.9 |
| | WT | Ironside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 0 | 0 | 0 | 0 | 46.8 | 42.7 | 44.1 | 11.6 | 8.2 | 9.6 |
| | | Birch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gun Range | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Leg | 0 | 0 | 0 | 0 | 2.2 | 0 | 0 | 0 | 0 | 0 |
| | | Fiesta | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Picard | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Teal | 0 | 0 | 0 | 0 | 1.2 | 1.2 | 4.6 | 2.4 | 0 | 0 |
| | | Gas Plant | 0 | 0 | 0 | 0 | 1.1 | 2.6 | 0 | 0 | 0 | 0 |
| | | Dog Paw | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix H - 3. Adult and young-of-year (YOY) wood frog (WF), western toad (WT), and boreal chorus frog (BCF) mean catch-per-unit-effort (CPUE: frogs/hr) of all visual transects (2-6 transects) for each lake in 2007. Eack sampling period is represented even if it was not included in analyses. Each lake was only visited once during each sampling period. Each period extended from the date given in the column to the day before the next column date (i.e., 26-June to 01-July, 02-July to 04-July).

| AGE | SPECIES | LAKE | PERIOD | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 26-Jun | 2-Jul | 5-Jul | 10-Jul | 13-Jul | 18-Jul | 22-Jul | 28-Jul | 31-Jul | 3-Aug | 6-Aug | 9-Aug |
| ADULT | WF | Ironside | 21 | 6.3 | 9.3 | 11.4 | 6.6 | 16.2 | 6 | 32.1 | 63.9 | 94.8 | 20.7 | 25.8 |
| | | Mitchell | 4.7 | 15 | 13.4 | 17.3 | 4.7 | 24 | 4.7 | 7.7 | 11 | 12.9 | 9.2 | 9.5 |
| | | Strubel | 17.4 | 1.7 | 6.3 | 4.8 | 3.2 | 0 | 13.8 | 0 | 8.1 | 47 | 11 | 11.3 |
| | | Yellowhead | 219.7 | 20.4 | 14.8 | 21.4 | 12.8 | 7.1 | 10.8 | 7.2 | 19.3 | 7.3 | 9.8 | 6.4 |
| | | Birch | 13.4 | 12.2 | 7.8 | 13.3 | 8.8 | 8.6 | 11.2 | 8 | 8.2 | 20 | 8.4 | 19 |
| | | Gun Range | 2 | 6 | 0 | 10 | 0 | 0 | 0 | 6 | 8 | 20.6 | 26 | 4.2 |
| | | Dog Leg | 5.2 | 14.4 | 3.8 | 10 | 10.4 | 18.2 | 24 | 14 | 45.4 | 41.4 | 5.2 | 21 |
| | | Fiesta | 12 | 10.4 | 0 | 9.8 | 8.2 | 10.2 | 4.4 | 6.2 | 22.2 | 27 | 13.8 | 20.4 |
| | | Picard | 6 | 6.6 | 14.7 | 4.4 | 14 | 1.5 | 2.7 | 4.4 | 38.7 | 25.1 | 19.4 | 33.9 |
| | | Gas Plant | 9.7 | 2.4 | 11.4 | 3.5 | 2.4 | 0 | 6 | 1.2 | 10.9 | 24.8 | 6 | 6.5 |
| | | Dog Paw | 0 | 6.3 | 10.8 | 11.1 | 0 | 3 | 17.7 | 18 | 0 | 78.9 | 18 | 42.9 |
| | WT | Ironside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 0 | 0 | 1.8 | 1.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 1.2 | 4.9 | 1.3 | 0 | 0 | 20.3 | 2.3 | 2.4 | 0 | 3.8 | 0.6 | 0 |
| | | Birch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gun Range | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Leg | 0 | 0 | 4.2 | 1.8 | 0 | 0 | 4.2 | 0 | 1.8 | 0 | 0 | 0 |
| | | Fiesta | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | | Picard | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix H – 3 continued.

| AGE | SPECIES | LAKE | PERIOD | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 26-Jun | 2-Jul | 5-Jul | 10-Jul | 13-Jul | 18-Jul | 22-Jul | 28-Jul | 31-Jul | 3-Aug | 6-Aug | 9-Aug |
| ADULT | WT | Gas Plant | 1.2 | 0 | 0 | 0 | 0 | 2.4 | 2.4 | 0 | 0 | 1.8 | 0 | 0 |
| | | Dog Paw | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.4 | 0 | 0 |
| | BCF | Ironside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 | 1.2 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 0 | 1.2 | 1.2 | 0 | 0 | 0 | 2.4 | 0 | 0 | 1.2 | 0 | 1.2 |
| | | Birch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2.4 | 0 | 5.4 |
| | | Gun Range | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.8 | 1.8 | 4.2 | 3 | 0 |
| | | Dog Leg | 0 | 0 | 0 | 0 | 0 | 0 | 13,8 | 13.8 | 12 | 0 | 2.4 | 0 |
| | | Fiesta | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.4 | 0 |
| | | Picard | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 15 | 15 | 11.4 | 6.6 |
| | | Gas Plant | 0 | 0 | 0 | 3.6 | 1.2 | 4.8 | 0 | 0 | 1.2 | 1.2 | 1.2 | 1.2 |
| | | Dog Paw | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 12 | 1.8 | 4.8 |
| YOY | WF | Ironside | 0 | 0 | 0 | 0 | 0 | 3 | 24 | 44.4 | 36.6 | 38.7 | 22.5 | 20.7 |
| | | Mitchell | 0 | 1.5 | 0 | 0 | 1.7 | 4.5 | 1.5 | 0 | 4.5 | 0 | 1.4 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.5 | 22.5 | 10.4 | 12.9 |
| | | Yellowhead | 2.5 | 0 | 0 | 0 | 0 | 4.8 | 3.2 | 1.2 | 5.9 | 10 | 3 | 1.9 |
| | | Birch | 0 | 0 | 0 | 1 | 2.3 | 7.6 | 19 | 34.6 | 16.1 | 44.5 | 20.2 | 15.1 |
| | | Gun Range | 0 | 0 | 0 | 0 | 0 | 9.8 | 0 | 0 | 18.2 | 16.2 | 37 | 12.8 |
| | | Dog Leg | 0 | 0 | 0 | 6 | 0 | 10.2 | 12 | 20 | 35.6 | 15.6 | 3.2 | 4 |
| | | Fiesta | 0 | 0 | 0 | 0 | 0 | 8.2 | 2.2 | 4 | 4.2 | 19 | 4.4 | 9.8 |

Appendix H – 3 continued.

| AGE | SPECIES | LAKE | PERIOD | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 26-Jun | 2-Jul | 5-Jul | 10-Jul | 13-Jul | 18-Jul | 22-Jul | 28-Jul | 31-Jul | 3-Aug | 6-Aug | 9-Aug |
| YOY | WF | Picard | 0 | 0 | 0 | 0 | 2.6 | 0 | 0 | 7.4 | 11 | 9 | 0.8 | 0.8 |
| | | Gas Plant | 0 | 0 | 0 | 0 | 3.6 | 10.8 | 22.7 | 10.8 | 20.6 | 20.4 | 3.5 | 7.7 |
| | | Dog Paw | 0 | 0 | 2.4 | 6.6 | 58.5 | 9 | 13.5 | 45 | 0 | 0 | 6.6 | 8.1 |
| | WT | Ironside | 0 | 0 | 0 | 0 | 0 | 6.6 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 3 | 7.2 | 0 | 0 | 0 |
| | | Yellowhead | 0 | 0 | 0 | 37.8 | 46.2 | 34.2 | 2.4 | 4.8 | 0 | 3.6 | 6 | 0 |
| | | Birch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 |
| | | Gun Range | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Leg | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.8 | 0 | 1.8 | 0 | 0 |
| | | Fiesta | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Picard | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gas Plant | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Paw | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | BCF | Ironside | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Mitchell | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.2 | 0 | 0 | 0 | 0 |
| | | Strubel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Yellowhead | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Birch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.8 | 0 | 0 | 0 | 0 |
| | | Gun Range | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Leg | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix H – 3 continued.

| AGE | SPECIES | LAKE | PERIOD 26-Jun | 2-Jul | 5-Jul | 10-Jul | 13-Jul | 18-Jul | 22-Jul | 28-Jul | 31-Jul | 3-Aug | 6-Aug | 9-Aug |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YOY | BCF | Fiesta | 0 | 0 | 0 | 0 | 0 | 0 | 4.2 | 1.8 | 0 | 0 | 0 | 0 |
| | | Picard | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Gas Plant | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Dog Paw | 0 | 0 | 4.8 | 2.4 | 3 | 0 | 10.8 | 0 | 0 | 0 | 0 | 0 |

Appendix I. Means (± SE) for catch-per-unit-effort (CPUE) for all three species and 2 age classes [adult (A) and young-of-year (YOY)] in 2005, 2006, and 2007, for stocked, unstocked and fishless treatments (2006 and 2007). In the fishless treatment, only adult and young-of-year wood frog means are displayed because the other species were seldom seen throughout the years. Snout-vent length means (SUL; ± SE) for adult and young-of-year wood frogs for 2005, 2006, and 2007 in stocked, unstocked, and fishless treatments. Data are not transformed. WF = wood frog, WT = western toad, BCF = boreal chorus frog.

| | | Species CPUE | | | | | | Species SVL | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | Year | AWF | YOY WF | A BCF | YOY BCF | A WT | YOY WT | A WF | YOY WF |
| Stocked | 2005 | 5.67 ±1.03 | 4.04 ±1.14 | 0.02 ±0.02 | 0.97 ±0.64 | 0.36 ±0.13 | 0.97 ±0.50 | 43.74 ± 0.80 | 24.22 ±0.18 |
| | 2006 | 9.33 ± 0.94 | 10.87 ±4.27 | 0.00 ±0.00 | NA | 0.07 ±0.07 | 5.48 ±2.48 | 39.99 ± 0.43 | 23.38 ±0.21 |
| | 2007 | 15.22±2.49 | 9.84 ±1.95 | 0.77 ±0.43 | 0.07 ±0.05 | 0.69 ±0.46 | 3.91 ±1.52 | 37.29 ± 0.76 | 24.21 ±0.22 |
| Unstocked | 2005 | 5.55 ±0.85 | 5.93 ±0.96 | 0.61 ± 0.18 | 1.04 ±0.65 | 0.22 ±0.10 | 0.06 ±0.04 | 42.86 ± 0.90 | 24.15 ± 0.23 |
| | 2006 | 8.69 ±0.70 | 11.18 ±2.39 | 3.44 ± 0.79 | NA | 0.32 ±0.11 | 0.42 ±0.17 | 36.67 ± 0.42 | 24.03 ± 0.15 |
| | 2007 | 11.58 ±1.53 | 8.51 ±1.18 | 3.01 ± 0.69 | 0.13 ±0.10 | 0.39 ±0.14 | 0.08 ±0.06 | 40.79 ± 0.95 | 25.07 ± 0.17 |
| Fishless | 2005 | NA | NA | | | | | NA | NA |
| | 2006 | 17.25±0.93 | 10.87±1.30 | | | | | 40.85 ± 2.54 | 25.09±0.52 |
| | 2007 | 17.59±2.90 | 11.00±2.60 | | | | | 43.14 ± 0.81 | 25.15±0.18 |